INTRODUCTION

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SOME PROBLEMS OF THE DAY IN NATURAL SCIENCE: AN INTRODUCTION

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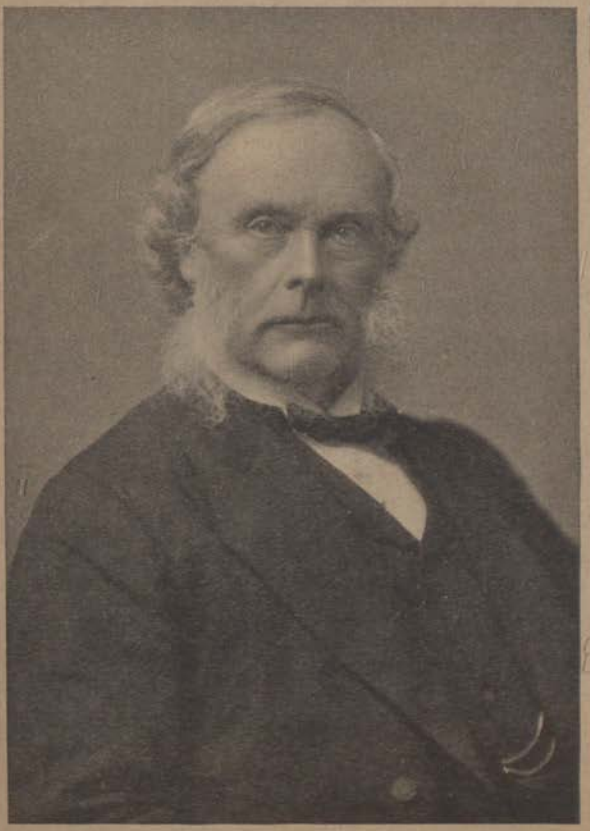

LORD LISTER, P.R.S.

From a photograph by Barraud

INTRODUCTION TO SCIENCE

BY ALEX. HILL M. D.

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PREFACE

This little book aims at giving an account in popular language of the scientific problems which are most prominent at the present time, and attempts to portray the attitude of mind of those who are engaged in solving them. It has small claim to the title An Introduction to Science. If it serves to give definiteness to the general impressions of any amateurs of science who have attended meetings of the various learned societies during the last few years, its object will be fully accomplished.

Since Bacon wrote his *Novum Organum* and Whewell issued it "Renovatum," the field of science has extended until it is no longer possible for any single student to survey it. Hardly can we hope that a second Herbert Spencer will extract the principles from all its provinces that he may blend them into a new philosophy.

If read without previous training or subsequent study, this book can hardly fail to be misleading; but it is intended as an introduction to a series of Primers in which competent teachers will treat in sufficient detail the problems of which I have attempted a bird's-eye view.

ALEX. HILL.

Downing Lodge,
December 1899.

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AN INTRODUCTION TO SCIENCE

SECTION I.

First Principles.

Definition of Science.—"Definitions might be good if words were not used in making them" is Rousseau's well-known paradox. Before any form of words can be found which will convey to the mind an idea of the meaning of science, the words themselves must be defined. Yet everyone knows what the expression "science" means, and appreciates its value as an amplification of the term knowledge. The idea of science as it hovers in the atmosphere of the mind has significance, difficult as it is to pin it down in words. "Science is knowledge reduced to law and embodied in system." The phrase sounds explanatory, yet each of its terms might be challenged; and it might well be asked whether our knowledge is "reduced to law" because our thoughts about the things we know are arranged in order in our minds. It might be pointed out that the force of the phrase is extrinsic rather than intrinsic, proportional not to its lucidity but to the experience of the individual using it of the applications of the word law, and his acquaintance with systems of philosophy. A definition should be at the same time an explanation; but the concise forms of words in which we attempt to define our mental conceptions resemble more frequently the analytical titles which the authors of the last century affected for their books. A formula does not necessarily inform. It may limit without elucidating, and often it carries but little information to those who have not already a considerable acquaintance with the subject.

Science is a synonym of knowledge; but a synonym which cannot be dispensed with, for it implies knowledge brought into value. It implies not only an acquaintance with phenomena, but a further knowledge of their similarity and dissimilarity. It implies a sense of relation and proportion among facts. "The professor's head is simply packed with facts!" "Yes," was the quiet rejoinder, "and they are all of exactly the same size." Science is knowledge in perspective. It is knowledge viewed down the vista of time: not an aggregation of facts presented simultaneously to the intellect, but a sequence of facts successively ascertained and placed in proper relation with all that was previously known. Science, therefore, connotes not an acquaintance with facts merely, but also the habit of drawing inferences, the mental training which enables the observer to link data together, and thus to make them fruitful as materials of thought.

Instead of seeking for a pithy expression, which at the end of our study will sum up its purpose and by defining the word "science" remind us of its scope, we recognize that the word "science" suggests to our minds the progressive accretion of knowledge in the past and the prospect of an expansion in the future, to which no limits can be put. The student of science sets out upon his quest with the intention, not of knowing only, but of understanding what he knows. He is not content with describing the form of an animal, the appearances presented during and after a chemical reaction, the sequence of events which together make up a physiological process; but he asks himself, Why this form and no other? What is the cause of the changes in this mixture? To what need of the organism does this physiological process respond, and by what agents is it brought about? The questions "What?" and "How?" always lead up to the question "Why?" Science is learning with understanding. The attempt to define its scope is likely to result in confining it.

Although all intelligent knowledge is science the term as commonly used has certain limitations. It is especially applied to the observation of natural phenomena and to the discovery of the laws which govern them, and hence it has come to be almost synonymous with inductive science. Pure speculation, if such a process be possible, belongs to the province of philosophy, which province also includes the deductions which result from the analysis of consciousness. In some usages we find the term "science" limited to the natural sciences, as for example when we speak of "a man of science." Yet, on the other hand, when the methods of science are employed in the elucidation of work which is strictly Man's and not Nature's, the use of the methods leads to the appropriation of the name. No one, for example, can assert of any event recorded in history that it is a fact, in the same sense in which a biologist is justified in describing a particular stage through which an egg passes in the development of a chick, as a fact; yet the work of an historian is said to be scientific when, wishing to supply an event which was not recorded by the chroniclers of the time in which it presumably occurred, he adopts the same inductive method which a biologist would follow if he wished to figure to himself a stage in development which for any reason it is impossible for him to observe. On the same grounds we speak of the "science of criticism" and of various other subjects, far removed from the study of Nature.

Reduced to its lowest terms, science is the observation of phenomena and the colligation of the results of observation into groups. By observation we discover that a particular fish is coloured like the seaweeds which grow on the rocks in the neighbourhood where it is found, and where we further observe it to be feeding. In other places where the growth upon the rocks is differently coloured, we observe that the fish are differently coloured but that they still resemble the seaweeds. From many similar observations giving the same result we formulate the "law," that fish which feed in the neighbourhood of rocks are coloured like the rocks and the

growth by which the rocks are covered. Asking the question "Why?" we are led to make an observation upon our own powers of sight, from which we discover that the resemblance in colour causes the fish to be less easily visible. Further, we observe that many other animals are coloured like their surrounding, and from these colligated observations we draw the conclusion that animals are coloured like their surroundings in order that they may escape notice. Again the question "Why?" is asked. Whose notice do the fish need to escape? We can think of only two alternatives. It may be an advantage to the fish not to be seen by their prey, or it may be an advantage to them to be invisible to their enemies. Additional observations with regard to protective colouring have to be made. It is found that a tiger marked by transverse bars is less easily seen against a background of tall grass and bamboos than an animal uniformly coloured would be; that the spots on a leopard make it less visible beneath the trees through which the sun is shining. These animals are practically superior to all enemies. They do not need to be rendered invisible to save them from their pursuers, but to hide them from the creatures they pursue. Is the same true of the fish? On the contrary, it is found that rock-feeding fish are preyed upon by many larger and more active kinds; and, further, a study of their food shows that the small shellfish and worms which compose it could not escape, were their tyrants never so conspicuous, and consequently the theory is propounded that the fish which feed near rocks are coloured like their surroundings in order that they may escape the notice of their enemies.

In all scientific investigations the same method is followed —observation, colligation, induction—and as soon as the stage of hypothesis is reached the process begins over again. Fresh observations are made with a view to determining whether the hypothesis will meet all cases. It is amplified to make it include allied phenomena, or modified to prevent it from excluding them. Perhaps it is rejected and replaced by an entirely different theory, because it cannot be

made to include phenomena which are evidently of the same order as those for which in the first instance it seemed to assign the cause.

It is easier to give expression to the general conception of science, as distinguished from knowledge, in metaphor than in a reasoned definition, and many comparisons which illustrate this welding together of facts with thought will occur to everyone's mind. Knowledge is a pile of bricks, science is masonry. Knowledge is a shower of separate raindrops, science the mountain torrent to which they give birth—the forceful stream which carves cañons in the rock, traces a green band on the map, turns water-mills, fills the reservoirs of dusty dirty towns. Knowledge is discrete, incoordinate, unsatisfying; science is concrete, coordinate, effective. With observation as the starting-point, the mind amasses knowledge, and knowledge by provoking thought leads to the acquisition of fresh knowledge out of which a wider thoughtfulness builds a scientific system.

The aim of Science is to know Nature. As a merchant takes stock of his goods before he makes plans for placing them on the market, so the student of science must make himself acquainted with the phenomena which Nature exhibits, in the province which he has pledged himself to explore, before he attempts to assign to them their several uses. There is no fact, no detail of measurement, of confirmation, of colour, scent, taste or distinctive marking which he dare overlook as too trivial for notice, however trivial may be the use which at the time he can make of his observation. All facts are great facts. Every observation which adds a fact to the sum of human knowledge is a great discovery. So too is every conclusion regarding the way in which non-living things react upon one another, or living things perform their functions, whether the induction result from passive observation or from experiment—from observation of phenomena under conditions which Nature has arranged, or from observations made under conditions arranged by the experimenter's art. Science asks first, "What is it?" next,

"How does it act?" then, "Why does it act in this way rather than in some other way?" And be it understood, this question "Why?" is asked with a view to eliciting as answer either that certain forces determine a change in the molecular constitution of the substance, or that the action serves the organism in such or such a way. Science never seeks to determine the relative value of phenomena in the scheme of the universe—in the Cosmos, as our intelligence figures it. Still less does science venture to suppose that she can throw light into the world above the world, the All-intelligent, of which our intelligence is but a dependence. The expression "The contest between Religion and Science" is an absurdity; there can be no contest in which one of the combatants is absolutely passive. With the struggle between what is true and what false in the expression of religion, in dogmatic theology, science has no concern; but this is a subject upon which we shall have a few words to add later on.

The aim of science is to know Nature, and to know for the sake of knowing. As has often been said of art, that it ceases to be art as soon as it is conscious of a moral purpose, so may it be said of science that when the student sets before himself a utilitarian object he runs the risk of prejudicing his conclusions. It is of course only in a limited sense that this is true. Great advances have been made by investigators whose object was wholly technical. Yet, if the history of science were written, it would be found that the first step in advance, the germ of the discovery which developed and became fruitful in the hands of the practical chemist, the mechanician, the pathologist, was discovered by the investigator for whom science lost its interest as soon as it could be put to practical use. Who anticipated until Lister devised its practical application that the septic infection of wounds inflicted by the surgeon's knife could be certainly prevented by performing the operation under a cloud of water-vapour in which carbolic acid is suspended? The antiseptic property of coal-tar had long been known

The chemist isolated phenol, which proved to be by far the strongest germicide of all the substances which coal-tar contains. Lister devised a method for investing cut surfaces with an atmosphere of phenol in which it is impossible for germs to live. How far was Röntgen, when he discovered—by accident, truly, rather than by design—that cathodic rays will penetrate organic substances, from foreseeing that he was equipping the surgeon with the means of detecting a bullet hidden in the flesh? We have taken our examples from the department of science of which the applications are of the greatest use to mankind, but similar illustrations are afforded by every subject of obvious practical utility. The discovery is made by the investigator who works without weighing the question of whether his line of research is more likely to benefit mankind than any other line. The practical man who is on the watch for suggestions seizes the discovery and applies it to the uses of his profession.

The superiority of pure science to applied science, as a field for research, is even more easily proved from the opposite side. Every investigator who works in a technical laboratory knows the difficulty of following a *useful* line of research. He is constantly thrown back upon himself with the conviction that only by some happy accident will he discover the solution to the problem; while at almost every turn in his investigations he starts questions to which he is astonished to find that no answer has yet been given, problems which tempt him to forget the purpose with which he set out, to leave the main road and to follow the by-path, not because he believes that it will lead him to a source of food or fame, but simply prompted by curiosity to find out whither it leads. It may be a pathologist who sets out to search for an antitoxin. He has no interest, of which he is conscious, in the chemistry of complex nitrogenous compounds. He will apply to the professed chemist for all the information he requires. But when his questions regarding the nature of the albuminoid constituents of serum are not satisfactorily

answered, he finds himself involved in a long research, which soon becomes an end in itself, and not merely a means to an end. A hundred similar illustrations might be given. But few scientific workers are still engaged, in middle life, upon the researches which they once thought the main objects of their existence. "The thoughts of youth are long, long thoughts!" At sunrise the distant peaks are clear, while the barriers which break the road that must be traversed ere their slopes are reached are hid in mist. At noonday the pass which has yet to be crossed before a camping-place is reached occupies a larger place in the traveller's thoughts than the loftiest of the mountains which lie beyond.

It may almost be said that science owes its progress to the deserters from the professions. A lad starts, as he is bound to do, to qualify as a manufacturing chemist, an engineer, a doctor. He discovers in himself an aptitude for one or other of the sciences upon which his profession is based, and he stays behind to work at the subject which interests him most; perhaps for a short time before pressing on towards his professional career, perhaps for life. It is for this reason that a school of pure science is strong only when it gives opportunities of passing on to professional work. The remarkable success of the scientific schools at Cambridge in recent years is largely, if not chiefly, due to the growth of the medical school. Every laboratory now has its complement of graduates who, while they may act as lecturers or demonstrators, give up the greater part of their time to research. Probably two out of every three of these men entered the University as medical students. But some found physics or chemistry, others botany or zoology, others physiology, anatomy, or pathology, of such surpassing interest that they abandoned all intention of practising medicine in order that they might give their lives to science. The growth of the engineering school is leading to a like result. And one cannot but regard the gain to pure science as far outweighing the loss to applied science. Pure science cannot hope for numerous recruits. Its prizes are few, its disappointments many, even

for those who show a special aptitude for its pursuit. The advice which we always give to a lad who desires to devote himself to science is, "Prepare yourself for a profession in which your favourite science plays an important part, and trust that if you have the capacity for the science you will secure the opportunity of pursuing it." Many a Cambridge graduate is now grateful to his teachers for urging him to persevere in obtaining a medical degree at a time when he wished to throw up every other prospect for the sake of one or other of the sciences upon which medicine rests. After taking the degree, he has returned to science to find that after all it would not provide him with a livelihood, or that his capacity for research was less than he had assumed, and therefore he has again given himself heartily to the profession from which for a time he thought himself seduced.

The aim of science is to know Nature, and the student can obtain an intimate knowledge of his science only by watching Nature's every manifestation. It is impossible to know her through report. It might be supposed that a man could become a learned chemist without entering a laboratory, but it is not so. There is in the writings of those who compile text-books without putting the statements which they copy from other authors to the test of experience, a want of accuracy and proportion which gives a false ring to the work. Everyone who has travelled knows that the thing as he saw it never exactly corresponded to the mental picture which written descriptions had caused him to draw. No one can convey in words to his hearer or reader an accurate conception of any phenomenon, even though he may have observed it himself, and the passing of the description through a second mind throws the picture still further out of focus. But it is not only in accuracy that the mental picture based upon descriptions is inferior to the picture formed from autoptic observation, but also in proportion. All facts are equally true, and yet every investigator knows that certain things which he observes in-

fluence his judgment more than others, so that when he is formulating a hypothesis he takes care that it squares with them. This perfect assurance of the indisputable accuracy of one's observations is a sentiment difficult to convey, and since in the higher branches of all subjects it is necessary to trust to the repute of observers in various special fields, it is of the greatest consequence that every one who assumes the position of teacher should have had such personal experience of research as will enable him to adjust the amount of credence which he gives to the reports of other workers. The supreme value of first-hand knowledge has been so much insisted upon of late years that it seems hardly necessary to accentuate it. The clearest definition of the aim of science is that it seeks to know Nature by personal contact.

From a personal intimacy with Nature results such a quick understanding of her manifestations as to constitute what in other spheres of thought would be termed intuition. The process of induction from observations occurs so quickly that the observer draws his conclusions as soon as he sees the phenomena. He is therefore able to foretell, with an accuracy which his ability to give the reasons for his opinion would not justify, what will happen next—what will be the result of certain novel combinations. Shall we call this scientific imagination? The term is self-contradictory, yet its use is in some degree justified by the analogy of art. Let it stand as a metaphor. To the man whose knowledge is partial and second-hand, the ease with which a specialist who has this personal and intimate knowledge of his subject can give the correct explanation of a phenomenon which he observes for the first time, or can judge between discrepant reports of observations, seems to be too rapid for reason; and the specialist himself finds, when he attempts to give his reasons, that they hardly justify the strength of his conviction.

Perhaps it is permissible to use the expression "scientific imagination" in a still larger sense. In the army of workers who are advancing the boundary of knowledge there are

some who gain for it a furlong, while others move it forward but an inch. And those who make the greatest advance do so because they bring to bear upon their subject the same mental qualities which constitute imagination in an artist. The artist imagines new combinations of form, colour, musical notes. The man of science imagines new combinations of force, new conditions of action. Some men are incapable of picturing anything outside the limits of their experience—others can devise new conditions and can foretell what would happen to inorganic matter or to a living thing if placed in circumstances which, so far as they know, have never concurred before. The development of an acquaintance with Nature so sympathetic and confidential as to allow the worker to share her secrets, and to unite with her in designing new combinations, is the highest result of scientific training.

The Boundaries of Science.—Science extends no further than knowledge. Its agents—the five senses—collect stores of facts upon which science lives and grows. It has no traffic with the unknowable; nor can it cross the border-line which separates the world of the senses from the world of consciousness, or barter its facts, gathered from the external universe, for the equally real facts which the individual ascertains by self-examination.

And not only is science limited to the world of sense, but even this world expands into a nebulous zone of half-science before the unknowable is reached. There is a limit beyond which scientific thought cannot penetrate; not because the outer realm does not appertain to science, but because experience which bears up thought with varying degrees of firmness—just as matter in its several conditions of aggregation, solid, liquid, gaseous, supports animals which stand, swim, fly—becomes too rarified a medium for human intelligence to mount in.

Much painful mental effort may be saved by the honest recognition of the limitations of science. A child, at the age when errant curiosity compels it to ask questions, and the simplicity of childhood believes that every question has

an answer, lies awake at night, beating its brains, in the struggle to understand what happened before time began; what space is like beyond the outside of infinity; and whether, if there be no outside to space, the comet, which travels fifty miles a second for a century, is not in the same place all the time. An astronomer is compelled to use the terms Time, Space, Movement; yet he is as little able as a child to form a mental picture of the absolute meaning of the words. He uses them so often, and they serve his purpose when explaining the sidereal system so well, that he forgets the date at which he abandoned the attempt to realise Time, Space and Movement as absolute—what? things or the attributes of things?—and settled down to speaking of them henceforward as relations.

The first step in chemistry or physics demands the recognition of a distinction between Matter and Force. But what is matter, and what force? Matter is that upon which force acts; force is that which acts upon matter. Yet it is late, if ever, that the physicist or chemist ceases his endeavour to form a nearer conception of the meaning of that which in its manifestations is the subject of his life-work. Time after time he traces the chain of inductions back, and still further back, to find himself before the weary paradox: that ultimate matter *is* force, and ultimate force is matter. The definite proportions in which "elements" combine together leaves the chemist in no doubt as to the ultimate constitution of matter. It consists of atoms ideally indivisible, because we can conceive of nothing which can divide them—although both physicist and chemist are beginning to regard the "atom" of Dalton as a cluster of atoms, or sub-atoms of matter, more fundamental than the elements; similar atoms unite into squads, or molecules, which are units of chemical combination. A binary compound is a combination of x molecules of one element with y molecules of another. The simple numerical relations between the various elements as regards their atomic weight and specific heat, which enables the chemist to arrange them into several

parallel series according to the "periodic law," leads him to the conclusion that there is only one kind of true atom variously united into groups by cohesive force. If there is only one ultimate indivisible atom there must be as many kinds of cohesive force as there are different "elements." "Impossible," the physicist exclaims; "there is only one kind of cohesive force. Either there are as many kinds of atoms as there are elements, or else, as is more probable, your atom is not matter at all, but a centre of force—for force is the one thing which you cannot think away, and the difference between one element and another lies in the amount of force which each centre, or atom, represents." The simplicity of the positions taken up by the most profound thinkers, when, after passing through abstruse and recondite processes of reasoning, they try to take a steady view of the ultimate constitution of things, would bring a smile to the face of a Greek philosopher accustomed to more generous theories. The most learned physicist becomes as a little child.

The biologist at an early stage in his career begins to ask himself, what is life? As age advances he finds that although he has learnt something of the ways in which life manifests itself, and can formulate an excellent definition of the means by which life maintains itself, he is farther off than ever from finding a form of words which will define what life *is*.

The psychologist, beginning with the study of the structure of the nervous system, passes on to the consideration of its modes of action, modifies the conditions under which it acts in every way which his ingenuity can devise, and patiently measures every measurable reaction-time; yet at the end of his work he exclaims, "But this is only reflex action. It was consciousness that I set out to investigate. All the researches which I have been carrying out serve merely to throw light upon the physiology of the nervous system. They teach me nothing about the working of the mind. Truly I have found out a good deal about the apparatus which the

mind employs, but I know as little about the mind itself as when I started." And when his four-year-old daughter, kissing him good-night, asks, "Daddy, where do I go to when I go to sleep? Do I go away from myself and come back again in the morning?" he answers humbly, "I do not know."

The candid recognition of the limitations of science can do no harm. Even within the proper sphere of science there is a level beyond which thought finds no foothold in experience, and there is another sphere, the sphere of consciousness, or the world of spirit—in the sense in which St Paul uses the term spirit, the "active reason" or intelligent soul of Aristotle—for which science has no passport. The methods of science may be used in investigating the phenomena of consciousness, but the use of her methods does not entitle science to claim the results. Even the use of scientific terms in describing spiritual phenomena introduces a grave risk of misunderstanding. Consciousness cannot perceive things outside itself. The phenomena of which it takes cognizance are its own varying states of exaltation and depression, activity and relaxation. We cannot measure love or hate, or duty in calories, or foot-pounds, or ampères, or any other units, and when we enter the realm in which emotions hold sway we have to leave our science behind. Perhaps this is the mistake which certain psychologists have made, who look upon man, body and mind, as merely the product of his environment. They regard him as a machine which responds in a rational way to every impinging force, whereas experience tells us that even the sterner sex seldom transmits the stimuli $2+4+6$ as an action equal to 12. An emotional bias almost always prevents us from working out the sum aright. No two persons obtain exactly the same result.

Science cannot penetrate into the world of consciousness. The writer of Natural Law in the Spiritual World showed a singular misconception of the meaning of the word law, as well as an inability to interpret either nature or spirit.

"There is," he said, "a sense of solidity about a Law of

Nature which belongs to nothing else in the world." But a law is nothing more than a docket into which we collect phenomena which have something in common. When it is discovered that certain facts are not isolated, but similar to certain other facts, they are united into a group which is held together by the character which they possess in common, and the statement that they all possess this character is enunciated as a "law." Early man discovered the law that stones fall to the ground; later it was discovered that water "seeks its own level;" that a heavy body when immersed in fluid displaces a bulk of fluid equal to its own bulk; that the moon remains at a fixed distance from the earth. All these apparently diverse phenomena fall into a group. We therefore tie them up with the same tape and put them into a docket labelled "law of gravitation." If asked for a definition of the Law of Gravitation, we state that "Gravity is a universal property of matter, in virtue of which every body gravitates to every other body; and the gravitations are proportional to the quantity of matter in that other body, and inversely proportional to the square of the distance from it." But this is not an explanation of the nature of gravitation, still less is it an explanation of its cause. It is merely the collection of like phenomena into a single group. As knowledge progresses other phenomena will be seen to illustrate the law of gravitation, or will demand inclusion with those phenomena which we have already enumerated in a common law. Hydrogen gas when liberated into the atmosphere is not attracted by the mass of the earth; on the contrary, it escapes from our atmosphere and flies off into space. But this does not invalidate the law of gravitation. The falling of a stone to the earth and the flying away from the earth of hydrogen gas must be ultimately due to a common cause. It is conceivable that some day the "law of gravitation" will be enlarged until its formula includes these apparently opposite phenomena; in which case it is not unlikely that scientific writers will find that the law in its new form is too wide for useful application. The phenomena which it comprises will be seen to

fall into two or more groups, the members of each of which have more in common with one another than they have with those in the other groups. New proximate laws will then be formulated within the law of gravitation. The docket "law of gravitation" will be subdivided, and the new dockets will include a greater number of phenomena than the "law" as now formulated can be made to do.

Not only did the writer of *Natural Law in the Spiritual World* mistake the meaning and value of law, but he was curiously obtuse to the trend of his own arguments. He found that an investigation of the spiritual world, as Christians understand it, shows that its "laws" are similar to those which man has formulated for the phenomena of nature. Mr Drummond found that in the supernatural world as revealed in the Bible, the laws with which we are familiar in the physical world hold sway. Had he found other laws—laws which have no counterpart in nature—he would have discovered a new line of evidence of the existence of the spiritual world. This new world, with its own laws, would be clearly an independent, self-sufficient world and not merely, as sceptics assert it to be, a reflection of the physical world—the projection of man's experience. "But," says Mr Drummond, "What is required to draw Science and Religion together again—for they began the centuries hand in hand—is the disclosure of the naturalness of the supernatural." "The position we have been led to take up is not that the Spiritual Laws are analogous to the Natural Laws, but that *they are the same Laws.* It is not a question of analogy but of *Identity.* The Laws of the invisible are the same Laws, projections of the natural, not the supernatural."

"God made man in his own image," says the Bible. "Man made God in his own image," answers Comte. Clearly, there is no third alternative. Either our religion is based upon a revelation of God, or it is our own invention. Nevertheless it may be that both statements are true. God made Man in His own image, and implanted in him the in-

stinct for feeling after Himself. Ever since Man became a rational being he has been trying to picture God. But still the truest picture is the one which carries most meaning to the individual, whether he approach it with ceremony, veiling its glory with a cloud of incense, or feel the familiar Presence by his own fireside. The analogies between the world of nature and the world of religion pointed out by Mr Drummond prove, if they prove anything, that much that Christians regard as a revelation is the product of imagination. Fortunately neither unwise friends of religion nor its overt enemies can prove that there is no supernatural world; but the book which we have referred to has done more than much hostile criticism in the direction of proving the anthropomorphy of the religion of the Bible. It demonstrates the intercalation of the fruits of human experience into the expression of religion. Pointing to the tool marks, Mr Drummond shows that our model of the temple was not made without hands.

"The antagonism between religion and science" is an absurd expression which was used most frequently after the publication of the "Origin of Species." Religious men of the last generation believed every statement in the Bible to be a statement of fact. Science proved that the earth did not come into existence in the stages described in the first book of Genesis; that the various species of animals and plants were not separate creations, that every organ in man's body shows that it has been adapted by a process of evolution from an organ of the body of an animal belonging to the "brute creation." Men who clung to the literal interpretation of the Bible, as essential to the Christian faith, fought against the truths of science. They preferred to disbelieve the conclusions to which their judgment came on the evidence of their senses. But science had no quarrel with religion. It was the false in religion quarrelling with the true.

The religious man may be a man of science or he may be unlearned and out of the way. If he is ignorant he sees no reason for not accepting scripture allegories as records of

facts; the picture is to him a glimpse into real life. A learned man, on the other hand, recognizes the pigments with which the picture is painted, and can trace the process by which the colours have been added to the canvas throughout successive ages. Yet the subject of the picture, the religious idea which it shadows forth is far more to him than it is to the ignorant man who gives to the details of outline and colouring a naturalistic interpretation.

It is with great reluctance that we have touched upon this subject, yet it has occupied so large a place in the thought of the last forty years that it cannot be passed over in a general survey of the history of science. Well-meaning but inept attempts at "reconciliation" have increased the difficulty of those who endeavour to be true to science and at the same time to hold fast in their allegiance to the Truth which is beyond the scope of science. It is only on this ground that we have ventured to point out a line of thought which as we think justifies us in keeping the two spheres distinct, and because we can imagine no process so likely to undermine the Spiritual World as the attempt to prove that it is governed by Natural Law. It is not within the province of this book to deal with spiritual ideas, or to suggest methods which may prove constructive in theology; but looking upon the question from the standpoint of scientific philosophy we have ventured to point out the harm which may result from a misconception of the meaning of the term by which similarity amongst phenomena is expressed. "Law" is a term which is applied to a sequence or a grouping of phenomena, only in a metaphorical sense. It is a convenient term which men of science use in classifying their observations, often as a synonym for hypothesis. They never intend to imply that Nature is bound by rules in the sense in which Man is. The misapprehension of the metaphor by persons who have not been trained in science, and by some who have been, has led to confusion; but it is difficult to think of any term which might replace it.

The German equivalent "gesetz," which really means a

statute, is still more open to objection. During the last forty years a steady outflow of books has been produced by champions, who, accepting the challenge of Comte and Huxley, have striven to justify their faith in the unseen by an appeal to the seen; and since the word Law is used by all these writers in a wholly unjustifiable sense, and since this question of the relation of religion to science has occupied many earnest minds, we have thus severely criticised the most mistaken and therefore the most harmful of all this series of apologetics. The worship of Law has done some harm in science. The introduction of the word into theology is fraught with graver dangers. It can but lead to an unworthy conception of the Deity. An absolute monarch is bound by no statutes. No laws stand between God and the phenomena of His creation.

Has science any quarrel with superstition? The question does not need an answer. Superstition is belief not founded upon knowledge. It is the product of the imagination of the individual suggested and supported by the traditions of his still more ignorant ancestors. The imagination does not devise objects which are contrary to knowledge. Its products are within the bounds of possibility as they are understood at the time. But as knowledge increases it is inevitable that some forms of superstition should be found to be contrary to this wider experience.

The educated have ceased to believe in elves and gnomes and hobgoblins, although there is a fringe of the population living in out-of-the-way places, where nature is vast and mysterious, who are still as firmly convinced of the existence of their banshees as more civilised country-folk are of their ghosts. Few of us, indeed, are quite convinced that ghosts are merely the products of the imagination. "There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy." It is a common and a reasonable answer, that while we trust our senses to tell us what *is*, it is useless to appeal to them when we wish for an assurance that certain things *are not*. Many a man when asked whether he

believes in ghosts is fain to answer in the words of the cautious Scot, "Weel, I wun'na say that such things cud'na be." No wise man would assert that ghosts cannot be. But a man trained in science has great difficulty in believing in the ghost as it is always described to him.

Some years ago a much-haunted house in Buckinghamshire was placed at the disposal of the Society for Psychical Research. No house could have afforded a better opportunity for the patron of ghosts to meet one of his clients. The ghost gave the best of references. Three clergymen vouched for it, one in a long affidavit. These gentlemen also asserted that the ghost was perfectly punctual and regular in its habits. Every night as the clock struck twelve it mounted the creaking stairs, entered the haunted room, deposited its pack on the floor (it was the ghost of a murdered pedlar), and uttered its formula—"Three stages more, and then comes death!" Several Cambridge men, including the writer, spent a solitary night in the room with the blood-stained floor—the blood was found on examination to be soluble in benzol, but that is a scientific detail—yet no ghost appeared. Not that the villagers' belief in their ghost was in the least shaken by what might be regarded as a base refusal on its part to substantiate their story. They were not even surprised at the disappointment of the seekers after truth. "What was the use," they asked, "of sending men from Cambridge to see a ghost? Why, they don't believe in anything in Cambridge!" Ghosts only show themselves to persons who are prejudiced in their favour, and at the Universities such a pre-possession is uncommon, it is to be hoped. The credulity implied by the villagers' word "believe" is not a scientific attitude of mind.

Now, without for a moment admitting that a scientific training deadens the senses to sights and sounds which the unscientific can perceive, we assert that loyalty to science compels us, whether we can or cannot see and hear the ghost, to ask for an explanation of its power of rendering itself visible and audible. Emission of light and production

of sound are exhibitions of force, and by the law of the conservation of energy—a law which cannot be called in question—force is never either created or lost. When it appears to us as a new force, we know that it is pre-existing force translated into a new form. The force set free on the combustion of coal came from the sun as radiant heat which enabled plants to decompose carbonic acid into carbon and oxygen. When coal is burnt the carbon and oxygen again unite, and the force which the plants stored up is set free. Whatever a ghost may be, it cannot create force. Further, we know that force cannot be exhibited except through matter. Light is emitted by a burning candle, sound by a vibrating violin string. Therefore the ghost which emits light and sound must be material. These difficulties do not occur to the simple villager, because to him force is not a reality. It is an attribute, not a thing. He can see no difficulty in supposing that a spirit can create force.

If we ask the more learned believer in ghosts the obvious question—Whence comes the force by which a ghost reveals itself?—he answers that the question is beside the mark. Every part of the body has its representation in spirit, and our spirit is capable of perceiving other spirits without the intervention of the senses. "No force passes from the ghost to you," he assures us. It is undoubtedly a thinkable position, so far as the body is concerned, but what about the clothes? Do they acquire a "spirit" by contact with a human being? If they do not, how is that the clothing of the ghost makes itself sensible to our spirits? Few chapters in social history are more interesting than the evolution of the ghost. It has steadily progressed in the wake—truly a long way in the wake—of science. Who can tell what the unexceptionable ghost of the twentieth century may be like?

Proficiency in science is shown by a masterly skill in cross-examining nature; and, as every lawyer knows, no case is proved as long as any antagonistic fact, however trivial, cannot be explained away. "The seeker after truth must himself be truthful, truthful with the truthfulness of nature. . . .

unscientific man is often content with the 'nearly' and the 'almost.' Nature never is." This was the doctrine preached by Sir Michael Foster in his address at Dover as President of the British Association. It is the first principle of science. Mathematics neglects the infinitely small. Common sense is content with an approximation to the truth, trusting, quite justifiably in the hurry of business, that much that it does not understand is capable of explanation. Science recognises no negligible quantity. "You don't seem astonished, Mr Brown, at the wonderful narrations of Deacon Smith," said widow Jones to one of two Yankees who were lounging in front of her fire. "No, ma'am, I'm a liar myself," was the laconic reply. One of the first things which science recognises is that all men are liars. We all inherit a tendency to believe in and, still more strongly, to narrate the marvellous. It is the business of the man of science to shake such narrations with simple straight-forward questions, to check them again and again by pointing out gaps in evidence, or barriers against evidence, which the narrator cannot cross.

We have already insisted that consciousness can be investigated only by consciousness. The senses are the "windows of the mind" which give upon the outside world. Consciousness is not force. We cannot find a place for it in the balance-sheet of the body. When we have audited its accounts — have debited the body with $x+y$ units of potential energy received in food, and have placed to its credit x units of muscular force and y units of heat; when we have debited it with $\alpha+\beta$ units of force received as vibrations by the endings of nerves in the sense-organs, and have credited it with α units of nerve force transmitted to the muscles through the central reflex mechanism, and β units consumed in effecting molecular rearrangement of nerve-tissue; we still find no place for consciousness. We cannot enter as "concerned in the production of consciousness" $\frac{1}{n}$ of the force received. And yet, although consciousness cannot be identified with either matter or force, it is at least as *real* as either. When we think

of the universe, these three realities stand forth: matter, force, consciousness. And as we know that matter is indestructible, it seems to us impossible to escape the conclusion that consciousness is indestructible also. We can no more conceive of it as coming out of nothing or fading into nothingness than we can conceive of matter or of force coming into existence or ceasing to be. And as the portion of matter which constitutes our bodies is but a part of a universe of matter, and as the force with which we are endowed is but a part of a universe of force, so, too, our consciousness seems to be but a part of universal consciousness.

How are we to know anything about the universal consciousness unless by revelation? Science has stopped short at the confines of the knowable. This is its boundary. It cannot proceed farther than the five senses. They give it no support in a region where there are no phenomena to be observed. The external relations of consciousness are known only to religion. Religion which must from the necessities of the case be expressed in human language, is represented by phenomena of the physical universe. To some minds the representation carries a more real, to others a more allegorical meaning, but the form in which it carries most meaning is, to the individual, most true. Science can throw no light upon religion in its inner sense. It cannot criticise religion. It can only recognise the existence of the other world and retire to its own domain; and as our subject is science, it is our duty also, having brought our argument to its proper limit, to cease from any attempt to follow it farther.

But what of the alleged incursions of the spirit-world into the physical universe; ghosts making themselves sensible to eye and ear, spirit-rappings, table-turning without the application of adequate muscular force, materializations, and all the other hocus-pocus of theosophy? Has science no right to resent the trespass? Of course it has. As soon as the phenomenon becomes a physical phenomenon it is the duty

of science to investigate it. It is the duty of the man of science to adopt such tests as Faraday adopted—to fix a false top to a table, with a manometer between it and the original top—and to show that the fingers which were supposed to resist the temptation to push, exercised the exact amount of force required to move the table; to devise the "control experiment" which has baffled so many clairvoyants; to search the files of telegrams until Madame Blavatsky's communications with India are found to be transmitted by no agency more marvellous than the electric telegraph. It is not for the man of science to adopt an attitude of either credulity or incredulity. Into the world of consciousness he, as man of science, does not claim admission; but matter and force are within his province, and his duty to investigate all phenomena which they exhibit is not in any way affected by the pretended mystery of the agencies which evoke them.

The Relation of Philosophy to Science. — In considering the boundaries of science, we have already anticipated some of the reflections to which this subject naturally gives rise; and we shall now be obliged, owing to the uncertainty of definition of the term philosophy, to return to some extent over the ground already traversed. In the present day the term philosophy is used in a relative sense. Herbert Spencer describes it as "knowledge of the highest degree of generality." The search for knowledge which is absolutely general has been abandoned. Since pure thought, independent of any particular application, depends upon absolute knowledge, it also is a logical fiction. It is the process of abstraction carried to the power of *n*. Absolute thought would be no thought, the sleep of the intellect; just as absolute knowledge would be no knowledge, ignorance: *Nihil est in intellectu quod non prius fuerit in sensu.* It is easy to show, with Leibnitz and Locke, that, however far thought may be removed from the basis of observation upon which it started, its independence of observation is only a question of degree.

Reasoning concerning the Absolute and the Infinite soon leads to paradox. An old friend of Professor de Morgan told me that, when the professor was harassed by people who pressed him to explain things which he felt that he could merely assert or deny, he would murmur: "The infinite circle is bounded by an infinite straight line." The boundaries of science and philosophy, when pressed to their ultimate terms, may be summed up in the same way: "Infinite science is bounded by philosophy," and *vice versa*.

We may, of course, set aside as immaterial to our subject the sense which was given to the term philosophy by the Stoics—a system of the principles of action which regulate conduct—a sense which still in its popular use clings to the name. The only meaning in which philosophy has any bearing upon our subject is that in which it stands for an organised system of thought of the most abstract kind; thought which pierces as far as possible through the visible husk of things into the principles which determine their particular manifestations. From the earliest times thinkers have not been content to believe that, when Man knows the utmost that can be known about phenomena, he knows the realities of which phenomena are the manifestations. Something unknowable is sought for behind the outward mask which alone is, or ever will be, seen by Man—a universal principle, a soul, a deity, "an actuality lying behind appearances."

With the philosophy of the Absolute a man of science has no concern. His province, as man of science, ends at the zone in which hypothesis can no longer be checked by observation or experiment. For working purposes he accepts the axiom that "all statements which cannot be confronted with objective tests are false." If no test can be applied to them they are equally true and false to him. Thinking about them is a waste of time. Science is the elaborated product of observation.

Yet, at the same time, the man of science, in common with thinkers trained in other ways, knows that he has two sources of information—his senses and his inner conscious-

ness. When reflecting upon the mental processes by which the materials supplied by the senses are worked into thought, the Mind is watching its own activities. By self-study a man acquires a knowledge of knowing, thoughts about thinking. He knows that he *possesses* consciousness. It is not that he is consciousness—merely a concomitant of a certain kind of nerve-activity. He owns a consciousness which he can direct and control; from which it follows that there is a He to own it. But the two sources of information must never be confused. The lines of thought for which the external and the internal respectively supply materials are parallel, and neither diverging nor converging lines. A man's consciousness gives him no more information with regard to his science, than his senses give him with regard to his consciousness. The two worlds are absolutely and permanently distinct.

Science prosecutes its researches to the confines of the observable. Self-analysis is carried to the limits of consciousness. Each line of research is abandoned with a sense that there is something beyond. Beyond the knowable, the Unknowable. Beyond the self-conscious, the All-conscious. It is in this *beyond* that the philosophy of the Absolute weaves its system. It is this *beyond* that religion seeks to explain. Religion claims indeed that the world behind sense and the world beyond consciousness are one.

"We know nothing beyond our simple ideas—which we are not at all to wonder at, since we, having but some superficial ideas of things, discovered to us only by the senses from without, or by the mind reflecting on what it experiments in itself within, have no knowledge beyond that, much less of the internal constitution and true nature of things, being destitute of faculties to attain it. And therefore experimenting and discovering in ourselves knowledge and the power of voluntary motion, as certainly as we experiment or discover in things without us, the cohesion and separation of solid parts, which is the extension and motion of bodies; we have as much reason to be satisfied with our notion of immaterial spirit, as with our notion of body; and the exis-

tence of the one as well as the other. For, it being no more a contradiction that thinking should exist separate and independent from solidity, than it is a contradiction that solidity should exist separate and independent from thinking, they being both but simple ideas, independent one from another; and having as clear and distinct ideas in us of thinking as of solidity, I know not why we may not as well allow a thinking thing without solidity, *i.e.* immaterial, to exist, as a solid thing without thinking, *i.e.* matter to exist; especially since it is no harder to conceive how thinking should exist without matter, than how matter should think. For whensoever we would proceed beyond these simple ideas we have from sensation and reflection, and dive farther into the nature of things, we fall presently into darkness and obscurity, perplexedness and difficulties; and can discover nothing farther but our own blindness and ignorance. But whichever of these complex ideas be clearest, that of body or immaterial spirit, this is evident, that the simple ideas that make them up are no other than what we have received from sensation or reflection; and so is it of all our other ideas of substances, even of God Himself." [1]

It is only when entirely freed from transcendentalism that philosophy has any part to play in the advance of science, and probably it would conduce to clearness of thought if the term were to disappear altogether from the scientific vocabulary. Nevertheless the adjectives "scientific" and "philosophical" usefully distinguish two aspects of thought; aspects which contrast in degree, although not in kind. By scientific is meant the slow advance from observation to observation, the stability of each fact being tested and retested before thought trusts it to support the simplest theory; by philosophical is meant the leap beyond the reach of ascertained fact and the subsequent search for facts in justification of speculation. Philosophical speculation takes a plunge, as it were, into the uncertain sea, trusting to reach firm ground

[1] Locke, *Essay concerning Human Understanding*, Book II., chap. xxiii., sect. 32.

again before its power of swimming is exhausted; whereas science, more cautious, builds solid facts into a causeway and never allows the waves of uncertainty to wet it above the ankles. Yet it is a question only of degree, for the shortest hypothesis which bridges across from fact to fact is in itself as wanting in solidity as the widest generalisation of which the human mind is capable; and the widest generalisation is equally with the narrowest but an attempt to unite isolated territories of solid fact. The process of reasoning is in the two cases the same; but the one regards certainty as the chief desideratum, the other aims at enunciating the theory which will embrace the greatest number of phenomena within its scope. "Scientific" and "philosophical" are not antithetical terms, for there can be no opposition between science and philosophy. It would be easy to show, seeing that the scientific process—the process of induction—is carried to the utmost confines of thought, that all products of human intelligence deserve to be classed as science; or, on the other hand, since knowledge acquires value only when worked into thought, the whole field of science might with equal propriety be assigned to philosophy.

The Senses the Agents of the Mind.—From very ancient times it has been recognised that the great brain or cerebrum is the seat of consciousness, thought, and volition. It may now be asserted that the cortex or sheet of grey matter which covers the cerebral hemispheres is alone concerned with these processes. The cortex cerebri is therefore the apparatus of mind. Prior to 1870 the brain was a mysterious organ, forbidding further physiological exploration. It was thought that it functioned "as a whole," and any attempt to analyse the constituent physiological processes of the act of thinking was looked upon as frivolous if not sacrilegious. Our mode of viewing the apparatus of thought has undergone a great change since 1870. Since then it has been shown—(1) that stimulation of particular areas of the cortex results in definite movements, while removal of the said areas is followed by paralysis for these movements, and

(2) that almost the whole of the cortex can be mapped into territories which are farmed by the several senses. It is true that a region is left in the front of the brain corresponding with the forehead, which cannot at present be associated with either movement or sensation; but, although its functions are unknown, there are ample grounds for believing that the mind makes no greater use of this region than of the regions behind it. For instance, this anterior region may be found to be healthy in cases in which the mind was most hopelessly deficient or deranged; or, on the other hand, this region may be extensively injured, and yet no mental deficiency be recorded. This does not show that it is not concerned with mind, since the same may be said of every other region of the cortex, but it proves that it is not the special or chief seat of mind.

If the brains of animals which are conspicuous for the great acuteness of one particular sense, or for its abeyance, be examined, it is easy to see which parts of the brain are associated with this sense; and it is possible to select such a series of animals as will show an excessive or deficient development of each of the five senses. A dog shows a vast development of the sense of smell; a marine mammal is totally destitute of this sense, for it is obvious that smell is a sense which cannot be employed under water. The eye is as useless underground as the nose under water, and it may consequently atrophy completely, as in the mole. An otter, twisting in and out among the snags and roots which border a dark brown peat-stained mountain stream, searches for the fish which "sulk," to use a piscatorial term, under the overhanging banks. Its eye is almost as useless to the otter as its nose, and it consequently relies for information chiefly upon the extraordinarily sensitive bristles of its cheek and lip. Again, anyone who watches a cat will see that its tactics when hunting are quite different from those of a dog. Its nose gives it general information of the proximity of mice, but it never follows a trail. Its ear tells it with such precision when to spring and in what direction, that the legend has

sprung up that a cat can "see in the dark." In truth its eye, which aids in hunting in daylight, is of much less importance to it when darkness approaches than its cheek-bristles which save it from contact with passive objects, and its ear which tells it when it is approached by anything that moves.

While carnivora trust either to the sense of smell, or, like the felidæ, to the senses of hearing and smell, in following their prey, herbivora trust to the eye for information as to the proximity of their pursuers. Observation of their habits would enable us greatly to extend the list of animals in which one or other of the senses is unusually efficient or unusually deficient. Those named above are but typical examples, and if any one of them which exhibits during life a great reliance upon a particular sense be examined anatomically, it will be found that—(1) the organ which serves this sense is obviously well developed; (2) the nerve which connects the sense-organ with the central nervous system contains an unusually large number of fibres; (3) that the territory in the brain which is allocated to this sense is more than usually extensive.

Anatomy and physiology have therefore in a remarkable way confirmed the truth of Leibnitz' dictum, "There can be nothing in the intellect which has not reached it through the senses." Metaphorically speaking, science has given an objective value to the intellect. It has enabled us to speak of the size and form of the brain when we indicate the extent and quality of the mind which uses it. Five instruments are played in the orchestra of thought: smell, vision, hearing, taste, and feeling, the last named being an organ with several claviers. Vibrations of various kinds strike the keys of these sense-organs. Those which call forth sensations of smell and taste are limited to the orbits of the molecules of odorous and sapid substances. Those which stimulate the organs of vision and hearing have an unlimited progression in space, the waves of light being "up and down" vibrations, which follow one another at the rate of hundreds of billions to the second, whereas sound is conveyed in the form of "to and fro" pulsa-

tions, which are not appreciated by the ear if they are more rapid than 40,000 to the second. An analysis of the several kinds of stimuli which affect the sense-organs of the skin would take up more space than we have to spare.

Light was first thrown upon the mode of working of the cerebral cortex by the discovery that by stimulating it with an electric current definite movements can be invariably evoked. This is commonly expressed by saying that it contains centres of movement. The discovery of its allocation among the several senses was made later. The question of the relation as cause and effect of the sensations which are received in the cortex and the movements which are originated by it is one of great complexity. Nevertheless, taking the most general view of the cortex as the organ of the mind, we may safely say that it is the nerve-tissue in which sensations are received and become conscious perceptions, and from which nerve-impulses for the evoking of muscular actions are despatched. In sleep and some other unconscious conditions these two terminals are placed in connection; sensations flow over into movement by reflex action. During the waking state the mind intervenes. Sensations become perceptions, and the mind, taking cognizance of these presentations of sense, decides whether they shall flow over at once into action or whether they shall be stored as memories for future use; whether flowing over with very little reinforcement they shall produce an obviously correlated action, or whether by combination with dormant perceptions they shall be expressed in a sequence of movements which seems, until it is minutely analysed, to be too complicated to result from a single presentation of sense. Whether or not, the mind perceives them, however, all sensations produce their effects upon the organism. Sensations which the mind perceives are the raw materials which it works into a product by which intelligence is made manifest. Mental action is a weaving of sensations into a pattern, and the expression of this pattern in act or thought.

If we try to figure to ourselves the mental activities of any

animal, we recognise at once that its thoughts must take the colour of the sense by which they are chiefly prompted. A dog, for example, does not recognise "a family likeness," but a family smell. In a day of happy wandering down the village street and through the lanes it pays no attention to the picturesque. As it lies in front of the fire, reviewing the experiences of the day, it recalls a long succession of suggestive smells. It is the cheek-bristles of the otter which vibrate with excitement as it remembers the slippery-sided salmon it nearly mistook for an alder-root. The cat twitches its ears as it dreams of bursting unannounced into a seminary of mice. If we wish in any degree to realise what our thoughts would be like if we were to exchange our brain for the brain of some other animal, we must ask first: Which of the five sense-organs is the one through which this particular animal chiefly looks out upon the world?

Before we set out to explore the world it is well that we should inquire into the credentials of the agents upon whom we shall depend for information. These agents are—

I. The Nose.—A poor thing to depend upon, and turned to base uses. We rely upon it chiefly to tell us when we are near drains or other receptacles for matter which experience has shown us to be noxious. We speak of such smells as "nasty." "Nice smells" are not for the most part nice in themselves, but scents which like musk, frangipanni, aromatic oils, etc., are peculiarly efficient in antagonising nasty smells; for the sense of smell in Man is almost useless for analysis; it can hardly distinguish one scent in the presence of another, still less can it resolve a combination into its constituent odours. How different it must be in the dog which can trace its master's footsteps out of a thousand, or follow them even when the master, to hide his trail, puts oil of bergamot on his boot-soles. By the time middle life is reached, even the small portion of our brain which is allocated to the sense of smell shows atrophic degeneration, proving that the sense is disappearing—as we might discover by careful observation; although as a

general rule, from force of habit and because we hardly ever call it into action we suppose that we still retain it. Its ever fading pictures still delight or shock us.

Stimulation of the olfactory membrane gives a "massive sensation." It is not marked by detail, that is to say. It is for this reason that scents (and the same is true in a less degree of tastes) recall scenes in a way which other sensations cannot do. The syringa which surrounded the summer-house in which we played as children, the jasmine beneath our bedroom window, the smell of warm pepper with which a particular sausage-factory reeked—we never smell syringa, jasmine, pepper, without recalling these vividly toned scenes. Anything seen with the eye or heard with the ear would have characters of its own, but the scent of syringa is the same whenever and wherever we smell it, and it must always be the background to the first strongly associated visual picture.

The olfactory membrane responds to the particles of certain chemical substances which have a comparatively rapid proper vibration, especially such substances as the essential oils. It cannot answer to a gas, of which the atomic weight is less than 15, nor to bodies of considerable atomic weight, such as the salts of the heavier metals.

Sight.—This is the sense upon which Man chiefly depends; and there is no reason to think that his eye, in its range of distance from objects near at hand to objects on the horizon, its power of distinguishing detail, or the accuracy of its colour-vision, is surpassed by that of any other animal. Yet the eye, considered as an optical apparatus, is extremely faulty; the several refractive media are not correctly centred, and are guilty of spherical and chromatic aberrations, besides a variety of minor faults. The layer in which waves of light are converted into nervous impulses (the rods and cones) is on the back of the retina, so that the picture is more or less obscured, like a photograph taken with the back of the sensitised paper in contact with the negative. But the picture which the Mind sees

does not present the imperfections of the image on the retina. By force of training, the Mind has come to ignore the faults of the retinal image. It does not take cognizance of the "blind spot" or of the yellow colour and double refraction of the "yellow spot," the only part of the retina which is sufficiently sensitive for "direct vision." Indeed the retina cannot be said to be very sensitive, since objects which subtend an angle with the eye of less than 60″ do not fall on separate "sensational units" of its surface. They fail to give rise to separate sensations, and are therefore seen, not as two objects, but as one. Since the retina is a mosaic of sensational units every apparently continuous line is really seen as a succession of points. Again, it is far from being capable of responding to all vibrations of light. There are vibrations slower and longer than the red and more rapid and shorter than the violet to which it is insensitive. And within its range, who shall say that it gives us correct information as to the relative wave-lengths of rays of light—the quality of the different rays which we distinguish as colour? The rays which produce the visible spectrum present, except for certain gaps due to the absorption of Fraunhofer's lines by the sun's atmosphere, every possible rate of vibration from 381 billions to the second to 764 billions; but the eye can distinguish them only as they coincide with or approximate to three mean rates. It groups them as red, green, violet, or combinations of these three colours in varying proportions. If, for example, the rays vibrate at the rate of 580 billions to the second, the eye says that they partake equally of the characters of red and green, with a very small trace of violet, and the brain gives to this combination the quality of yellow. We cannot imagine what the sensation—the colour—would be like if the eye contained a mechanism specially sensitive to the rays which, when stimulating equally the red mechanism and the green mechanism, are judged to be yellow.

Hearing.—A comparison of the cochlea of the human ear with that of animals shows that Man possesses an organ of hearing which is as elaborate in structure as any to be

found in the animal kingdom; and such observations as are available indicate that he can put it to far better use in the analysis of sound than any animal can. Indeed the most remarkable characteristic of the ear, as an organ for discriminating sounds of different wave-lengths, is its almost unlimited capability of improvement under training. An untrained savage cannot discriminate a difference of less than a semitone between two notes, whereas a trained musician detects a discrepancy of one-thirtieth of a semitone, or even less. And not only can the ear discriminate minute differences in rate of vibration, but it can in a very remarkable degree resolve compound waves of sound into their constituent waves. No tone which reaches the ear is a pure tone. Upon the vibrations of a certain rapidity which constitute its prime tone are superposed numbers of harmonic vibrations of rapidity greater than that of the prime tone in the proportions of $\frac{2}{1}$, $\frac{3}{2}$, $\frac{5}{4}$, and so on. The ear detects the presence of these overtones and recognises their relative preponderance, or the "quality" of the note produced by a musical instrument. As an analytic apparatus the ear is far more efficient than either of the other sense-organs.

Animals have little need of the power of analysing sounds. To a cat all mice squeak alike, we may presume; the cry of "Meat, meat!" suggests but one idea, though sung to diverse tones; emotions, not ideas, take possession of its soul as it listens to its lovers serenading it with the "song without a tune." Its ear fully performs its functions if it discriminates a limited number of widely different sounds. It is not the quality of the sound that interests an animal so much as the direction from which it comes, the distance away of its source, and the amount and character of the intervening substances by which it is muffled.

The ear gives to us but little information of the position in space of the source of sounds. Our external ears, instead of being long movable trumpets which collect sounds, and at the same time show their direction, are immovable appendages which may be lopped off without appreciably affecting the

value of our organs of hearing. Man uses the ear to but a slight extent as an organ for investigating the universe. He enjoys its great analytical power as an avenue, not to the outer world, but to the mind of his fellow-man as expressed through speech. Its external movable appendage has ceased to be of importance, but the analysing apparatus of the cochlea has been developed until it can distinguish several thousand different tones. The enjoyment of music is a remarkable illustration of the store which Man sets upon his power of distinguishing tones. It is a pleasure to use this sensitive mechanism for the recognition both of tones in sequence and of tones in combination. Pure tones and perfect harmonies are listened to with delight. Imperfect harmonies, which are difficult to analyse, and discords give pain to the trained ear. This is not the place to consider the meaning of music, or even to discuss the question as to whether it has a meaning, until by association we assign one to it; but it is allowable to point out in passing that the pleasure which we find in using the ear for the analysis of musical sounds confirms our statement that it is for this purpose that Man values it. Compare for a moment the ear with the eye. Several pure colours flashed at the same instant upon the retina produce but one mean effect, which might have been produced by a single colour. The eye has no power of analysing super-imposed vibrations of light. A harmony of several colours is to the eye what a melody is to the ear. The eye is for the recognition of position in space; the harmony of colours must be stationary. A sequence of colours is not only not enjoyable, but actually painful. The ear, on the contrary, reports sequence in time, and has hardly anything to do with position in space.

Of taste and of "common sensation" we need say but little. The former has so personal an application in deciding what we shall swallow that it can hardly be said to give us any information as to the properties of the things which belong to the external world; the information reaches our brain only at the moment when these things are passing into our inside selves; while the latter in its several varieties of

sense of touch, of temperature, of pressure, and of muscular exertion, gives us information chiefly about our outside selves. But concerning the sense of touch used in conjunction with the sense of sight much might be said; for it is to this co-operation that we owe all that we know as to the shape and position of the objects by which we are surrounded. To take a simple illustration. A flash of lightning illuminates the interior of a darkened room. We see it as a space bounded by walls and occupied by various solid objects; for thus we interpret the image formed on the two retinae of our eyes. But if this illuminated room were the first thing seen by a blind man it would convey no meaning to his mind. His sense of touch would have told him that the room is bounded by walls and that it contains solid objects. But he would be unable without training to correlate what he had felt with what he now saw. His eyes, used now for the first time, show him a flat picture; they give him no information regarding the third dimension. Suppose that in this room there is a round ball resting upon the table. The man's right and left eyes each show him a flat picture with a certain incidence of light and shade; but the two pictures are not the same. The right eye sees more of the right of the ball, the left more of the left. Each picture is clear in outline, yet when the two pictures are superposed it is only at the two poles of the ball that the outlines of shading coincide. Yet to those who have always enjoyed the sense of sight the two eyes do not give a blurred picture of a spherical object, even though it be illuminated but for an instant by a flash of lightning, but one clear in outline, and that not the picture of a flat disc but of a solid sphere. It is not the eye but the finger that has taught us that the ball is solid. We have learnt to associate the superposition of two non-coinciding retinal images with the extension in three dimensions of an object. And so well has our Mind learnt this lesson that instead of seeing a blurred picture, we *see* a clear-cut presentation of a sphere. Artists know that in painting a round ball they must progressively increase the blurring of the lateral outline from the poles to

the equator; but it is dangerous to go far in this attempt to delude the eyes, since it can only produce the right result when viewed at one particular distance from the canvas; and even at the right distance the two eyes soon find out the fraud. The brain paying attention in rapid alternation to the images transmitted through the right and left eye respectively discovers that they are both blurred, not clear when viewed separately, and blurred when superposed. A seascape painter is reported to have said that the compliment to his artistic skill which he felt most keenly was paid him by an uncultured country friend. Attracted to his studio by a heavy thud upon the floor, he entered just in time to see his friend's boots projecting through the canvas of his last and most successful picture of a deep, clear, sun-lit pool. So perfect an illusion had his art produced that his friend had given way to a natural impulse and "taken a header." It requires but little physiological knowledge to enable one to draw the conclusion that the too impressionable connoisseur of sea-scapes was a one-eyed man. Art cannot deceive the two eyes, because the conflict of their presentations which, but for the sense of touch, would result in confusion, has as it were added a new sense of the position and shape of objects. Thanks to the co-operation of eye and hand we enjoy a sense of tacti-vision which, by long training, we have learnt to exercise without sacrificing the sense of vision pure and simple. We see with the clearness of the lower vertebrates, birds, reptiles, and fishes, in which vision is mono-scopic, although we, in common with monkeys and some other of the higher vertebrates, have acquired the power of stereoscopic vision.

Extension of the Senses by Artificial Aids. — Our senses would teach us little of the world in which we live if their capacity for collecting information were not increased by artificial means. By placing a lens or a system of lenses before the eye, the image thrown upon the retina is magnified and our power of distinguishing detail proportionately increased. A magnification of 1000 diameters is equivalent to the subdivision of each "sensational unit"

of the retinal surface into 1,000,000. By collecting waves of sound in a concave reflector, their effect upon the drum of the ear is intensified. The microphone renders audible sounds as faint as the footfall of a fly or the beating of a frog's heart.

More important than the apparatus which has been devised to aid the senses by increasing their power are the instruments which have been invented to take their place—instruments which are sensitive to a degree to which no organ of the body, however aided, could attain. Differences of electricity (it seems almost strange in these days that the body is not equipped with any organ which can respond to this mode of motion!) heat, light, colour, weight, chemical reactions of extreme minuteness, are recognised by these instruments of precision and—a matter of even greater importance—they are registered in a permanent form so that the investigator can refer to them at his leisure. "Science is measurement." Much of the credit of its advance is due to the instrument-maker.

A list of the instruments of precision which are at the service of workers in various branches of science, with a comparative statement of their delicacy would be of great interest. But such a list would be misleading unless elaborate explanations were given of the conditions under which they can be used with their maximum of sensitiveness. For example, a microscope fitted with an objective of $\frac{1}{18}$ inch focal length and an eyepiece multiplying twelve times will give a magnification of 3000 diameters. Yet it is rarely that so high a power can be usefully employed. Clearness of definition is to a certain extent sacrificed to magnification; the loss of "penetrating power" restricts the use of such a combination to sections of the extremest thinness and most vivid staining.

Delicate apparatus for testing and examining objects exact great nicety in the preparation of the objects for examination. In no case is the recent improvement in method more conspicuous than in the preparation of sections for the

microscope. Thirty years ago the histologist placed the specimen of which he wished to prepare a section between two pieces of cork or elder-pith, and cut it with a razor which he held in his hand. Now he has microtomes of many patterns to choose from. He may embed the object in celloidin, soak the mass with water and cut it frozen; or he may embed it in paraffin and cut it on a riband-microtome —a section-cutter, so named because the slices of paraffin are caused to adhere to one another at their edges, making a continuous riband. The steady hand upon which the microscopist used to pride himself is no longer required. A laboratory boy turns a handle, or the machine is connected with some form of motor and sections fall away from the razor in a band of paraffin which can be mounted almost automatically on glass slides. Nor is it necessary to mount every section. The machine will select one in five or one in ten and thus save unnecessary labour in their examination. A worm an inch long may be cut into thirty thousand sections by an assistant who has no knowledge of anatomy, and comparatively little technical training. And not less remarkable than the improvement in cutting sections is the improvement in staining them. Again the investigator can delegate to an assistant technical work which used to consume the greater part of his own time; in this work, however, there is hardly a limit to the development, by practice, of the attendant's skill. Years of training are needed to make him master of some of the more complicated methods of colouring sections of nerve-tissue.

Closely associated with improvements in methods of manipulation and observation is the increased control which the observer has acquired over the conditions in which his observations are made. He can vary the temperature from the point at which hydrogen becomes a solid body, within 16 or 17 degrees centigrade of absolute zero (below which there is no greater cold, for molecular motion ceases altogether) to the heat of the electric arc in which the most refractory metal passes into the gaseous state. In regard to temperature,

therefore, it may almost be said that his experiments may range from the lowest to the highest possible limits. Over pressure, electric tension, light, his control is almost equally extensive. He is no longer compelled like his predecessors in the field to conjecture that, if it were possible to make an observation under certain conditions, the results observed would be thus or thus. No sooner does his argument lead him to infer a certain result than he enters his laboratory, and, having arranged the conditions, brings his hypothesis to the bar of experience. Nay, not only can he command almost every combination of conditions, but he can press into his service almost every substance which can exist. Compounds which have never been found in nature and have never been formed by art are as much at the chemist's disposal, when he wants them, as if they were already ranged in neatly labelled bottles on his shelves. He knows their formulæ, their atomic weight, and specific heat, and much regarding their properties, before he has made them, and whenever it may suit his purpose to make them, the steps of the process will not be sought for tentatively and with misgiving, but followed with the assurance that they must inevitably attain the desired result.

These statements as to the power of science are mere platitudes. We stop perhaps too frequently to wonder at our own success in subjugating nature and the exceeding rapidity of its recent advance. Yet advance brings us no nearer to the end of our labours, for the more we know the more we see of what remains to be known. Every problem laid at rest gives birth to two new problems which did not present themselves to the mind before. Anyone entering the field now is assured of work to do, and of immense physical resources to aid him in doing it. But probably the attitude of mind of a recruit to science is, or should be, very different now to that of the long army of fighters who have gone before him. Here and there we may pick out from amongst the pioneers of science a Cavendish, a Faraday, a Robert Brown, whose ambition it was to know more of things near at hand; but the greater number took up their

work with anticipations which were less easily to be fulfilled. To go back no farther than Huxley, or his favourite model Descartes, the study of science was undertaken in the hope of obtaining a wider view of the universe and a clearer conception of what does or does not lie beyond, "to learn how to distinguish truth from falsehood, in order to be clear about my actions, and to walk sure-footedly in this life." [1] No one nowadays can hope to gain a comprehensive view of science as a whole, still less to abstract from his science lessons which will guide him in shaping his course in life. The great struggle through which Huxley lived is over. Science, philosophy, religion, are no longer engaged in a triangular duel. The man who mines for gold is in no way concerned with the analysis of the emotions which decide a rich man to spend it upon himself or to give it in charity. The recruit to the scientific mine must be content to push forward his adits and galleries in the direction in which gold is supposed to lie, with no thought of the use which will be made of the coined metal, and no expectation of driving his tunnel to the far side of the mountain and catching a vision of the beyond. Nowadays we want to know because we want to know. Philosophical generalisations, in the sense of a guide for conduct, which still clings to the word philosophy, are no longer looked for from science.

Classification.—Comte classed the sciences as abstract and concrete, and this sub-division is generally followed. Among the abstract sciences Comte placed logic and mathematics which treat only of the form in which phenomena are known to us—their sequence in thought and their relations in quantity—not of the phenomena themselves. All other natural sciences he regarded as concrete.

Herbert Spencer points out with justice that, while the abstractness of the first group is indisputable, the sciences of the second group are not wholly concrete, and he removes

[1] "Methods and Results." Essays by T. H. Huxley, p. 168. A quotation from Descartes' "Discours de la Méthode pour bien conduire sa Raison et chercher la Vérité dans les Sciences."

mechanics, physics, chemistry, etc., into an abstract-concrete group, because they lead the natural philosopher to the purely abstract conception of force *per se* apart from its manifestations in the various modes of motion—heat, light, electricity, etc.

But this distinction is too philosophic, if we may use the expression without offence, for scientific thought. Force apart from its manifestations is only a conception, although a necessary conception of the human mind. It has its starting point in the mind, and expresses the attitude of the mind towards the phenomena of which it takes cognizance. If we try to conceive of force, except in its several exhibitions, as modes of motion, we soon reach the vanishing point in which the material of thought disappears, and nothing remains but its clothing, the terms in which thought is dressed. The horny-brained son of science acquires a habit of marching every claimant for a place in the world of facts and every newly derived conclusion up to his dissecting table, his microscope, his balance, with a curt demand to show itself for what it is. Small wonder if he grows impatient of phantoms which walk over the pan of his most sensitive balance, past his photographic plates, and through his electroscopes without leaving a record. He doesn't deny their existence. Why should he? But without looking up from his work he grumbles that it isn't his business to weigh the imponderable or to measure the all-pervading.

Physics and chemistry deal with matter, the action upon matter of force, and the resolution of force by the influence of matter. Sublimated from matter these sciences pass over the boundary between physics and metaphysics. In their abstract form, independent of phenomena, they resolve themselves into a study of terms. As long as they are based upon knowledge they are concrete.

It is somewhat unfortunate that subjects which are so little congruous as mathematics or logic, and the physical sciences, must be included under a general designation and classified as members of one group. Comte in his classification was not using the terms "abstract" and "concrete" in a strictly

logical way, for he speaks of "two kinds of natural sciences —the one abstract, general, has for its object the discovery of the laws which regulate the diverse classes of phenomena, taking into consideration all the cases which can be conceived; the others concrete, particular, descriptive, which are sometimes designated as the natural sciences properly so-called, consisting of the application of these laws to the effective history of the different existing things." Herbert Spencer points out that "abstract" and "general" are terms which cannot be compatibly applied to the same class. "Abstractness means detachment from the incidents of particular cases. Generality means manifestation in numerous cases," and it is evident that the comparative isolation and specialty of phenomena or their generality do not make the sciences which deal with them concrete or abstract.

We doubt whether anything is to be gained by classifying the sciences. They are mutually dependent, and pass without definition one into the other. The study of the formation of starch in a plant belongs equally to chemistry, botany, and solar physics. But while, philosophically speaking, there is but one Science, the cultivation of Science has led to the allocation of particular parts of its field to particular classes of men. The students of Science can be classified with more success than the sub-divisions of knowledge which they severally endeavour to make their own.

If we attempted to picture the tree of Knowledge we should sketch it somewhat as follows: At the base, where it rests upon the ground, (1) the observation of the physical properties of familiar objects. The description of these objects and the comparison of their properties require the exercise of thought. The endeavour to think clearly and to express consistently, gave rise, long before any such science was formulated, to (2) the twin trunk *Logic*. Among the properties of the objects examined, were certain relations in number and extension. As soon as mere counting and measurement were accomplished, and numbers and extensions were imagined apart from things numbered or

measured, a thick stem branched off from the tree of knowledge, as (3) *Mathematics*. The bole then divided according to the kinds of phenomena observed into (*A*) the study of the movements of the heavenly bodies, *Astronomy*, and (*B*) the study of the earth. The force which holds the heavenly bodies in their place was subsequently investigated by the physicists, and their constitution, as shown by the spectroscope, by the chemists. The earth may be looked at as a whole, (α) *Geology*, or in its constituent parts. The parts are non-living and living. In the consideration of non-living things attention may be paid to matter, (β) *Chemistry*; or to the exhibitions of force through matter, (γ) *Physics*.

As the study of the several modes of motion is to the study of the combinations and changes of state of matter, so is the study of physiology to that of the structure, development, taxonomy and distribution of living organisms including Man. *Biology* (δ), therefore, includes one group of subjects and (ε) *Physiology* another; while the study of function leads to *Psychology* (ζ), and this to (η) *Ethics* and (θ) *Æsthetics*. The applied sciences must take their places under one or under several of these sub-divisions. A special application does not constitute a special science. Nor does the borrowing of materials, or methods of study, create proprietorship of such materials or methods. Solar spectroscopy is not astronomy, nor palæo-botany geology.

Of all the sciences, if each is looked at as a whole, astronomy is the most concrete. Yet before Neptune had been observed its existence was inferred by Adams as the cause of the perturbations of other planets. It may almost be said to have been a mathematical product in Adams' mind. Though, of course, this is merely a figure of speech, for the cause of the perturbations was at all times in his thoughts a concrete thing; but it illustrates the way in which for the astronomer the heavenly bodies may almost lose their objective reality apart from his calculations.

When we look at the sciences which treat of the world, its constituents, and inhabitants, and the forces to which they

react, we see that, as physics becomes abstract in proportion as phenomena are left behind and the ideal conception of force is approached, so the biological sciences become abstract when they attempt to explain the nature of life. Life is to the manifestations of life what force is to the manifestations of force. No definition of life does more than specify in the most generalised way the qualities which distinguish it from non-life. When Herbert Spencer defines it as "the co-ordination of action" he does not bring into his definition the source or cause of the co-ordination which, from the philosophic standpoint, should be of the essence of a definition of *life* as distinguished from *living*.

Looked at as comprehensive of all living things, and not as peculiar to the individual, Life might be better defined as "the continued adjustment to environment," since upon the exhibition of this tendency to adjust, in a higher or a lower degree, depends the increase in the amount of life in every particular form, or its decrease and eventual extinction; but, again, our definition is a generalised expression for the manifestations of life without reference to its cause.

In attempting to distinguish between life and its cause we are coming dangerously near to the old doctrine of "vitalism," with all its barren side-issues. Is it not better for the man of science to say, "Matter, Force, Life *are*," without attempting to conceive what they are? Let him push forward his investigations as far as observation and reason can advance, and construct hypotheses as to what exists beyond the outposts of knowledge, only so long as the hypotheses are or ever can be verifiable, because such hypotheses are the guiding lines of further research; but a speculation which from the very nature of the case is unverifiable is no better than a delusion.

History of Science.—The history of the inductive sciences was brought down to 1846 by Whewell in his second edition. No single man is competent to deal with their further progress, collectively, since that date. It is a tradition with the writers who undertake the several branches of science for the "Encyclopædia Britannica" that they should

preface their accounts with a short historical review. Many of these histories are excellently written and fascinating to read. But their attraction lies as much, perhaps, in the record of the mistakes of men of former time as in their discoveries and prophesies since verified. The pertinacity with which men clung to theories, ballasted with authority rather than freighted with proof, seems strange in these days when every A.B. is his own navigator across the Sea of Science. But this respect for authority must be allowed for in studying the history of knowledge. It is not, perhaps, altogether to be condemned. Nor should the errors of the "men of old times" lead us to undervalue the intellectual force of the men. The tendency of us moderns is perhaps towards immense knowledge and hasty, ill-considered generalizations. Meagre conclusions from abundant data rather than wide conclusions from meagre data. It is the inevitable result of the vast accumulation of knowledge and the multiplication of workers engaged in research. As we sometimes wonder when the increase of traffic in front of the Mansion House will lead to its arrest, so are we tempted to ask whether the prosecution of research will not some day cease altogether, owing to the multiplicity of workers and the consequent impossibility of any one informing himself as to the work which others have done. Every man who is engaged in research knows the sinking of heart which occurs when he decides to publish. Publishing involves the "getting up of the literature," which perhaps reveals the fact that all that he proposed to announce to the world has been anticipated by some one else. A new discovery is a discovery new to me. Its interest does not necessarily vanish when I find that I am not unique. Nothing but the prick of vanity or the pressure of self-interest would induce a scientific worker to face the drudgery of going through all that the competencies and incompetencies of every tongue have written on his subject. The quiet academic student who recognises no responsibility towards the public to make known his results, and feels no sense of gratification in substantiating a claim to priority, is often to be envied.

The history of human progress is at the same time the history of error; but both progress and error should be considered in relation to the total extent of knowledge and the opportunities which at the time existed of checking speculation by observation. If it were possible to construct a diagram showing the extent in every age of the means of attaining knowledge, and the deviations from truth, and approaches to truth of natural philosophers; and then to express the attainments of each epoch as fractions, with the mean truthfulness as numerator, and the opportunities of reaching truth as denominator, it is possible that the result would not be creditable to the present generation. Anyone reading the history of science should form such a mental diagram in which the man with unaided senses, the Greeks, Romans, Arabs, scholars of the seventeenth century, the eighteenth century and the Victorian Age, take their places. Their attainments ought never to be appraised except in relation to their opportunities.

Ample materials are to be found in the "Encyclopædia Britannica" for studying the history of science. We have space only to ask what is the most impressive burthen of such study. The great gain which the ages have brought to science is the increasing purity of aim of its votaries. Formerly knowledge was a means to a practical end. Now it is an end in itself. To take a simple illustration from the history of chemistry. The ancients were acquainted with a certain number of substances, some of which when placed in water passed into solution; some when ignited disappeared in flame; some when heated with charcoal were resolved into an earthy calx and a bright metal. They had no conception of the part played by the atmosphere in combustion—a substance when burnt disappeared in flame. They had no clear notion of the nature of a compound—matter when combined with other matter was transmuted into new matter, a change in its nature was marked by a change in appearance and properties. What conclusion more rational than that matter could be created and destroyed, that

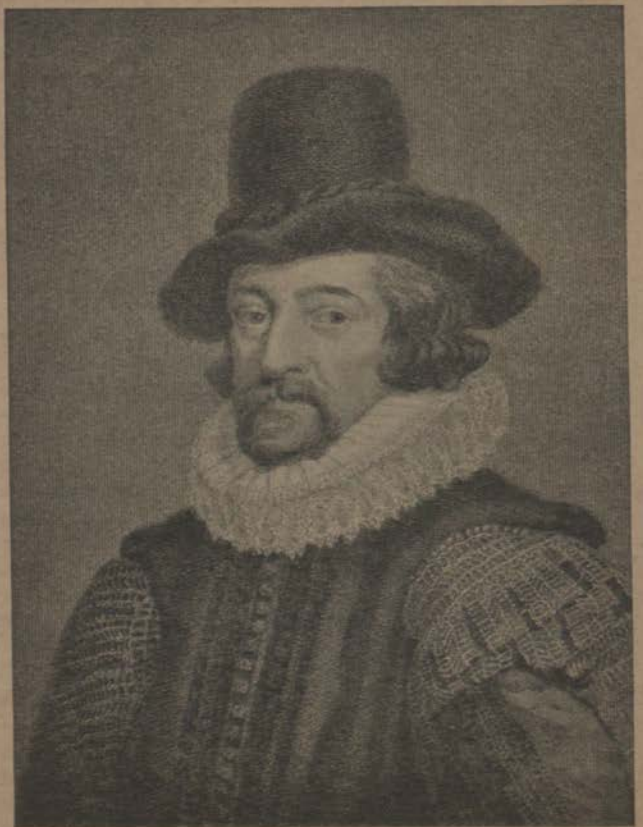
it was protean, any substance being changeable into any other substance by a series of transitions, if only the right means were employed? The doctrine of the indestructibility of matter—essential as it seems to us as a first principle of science—has not been established for much more than a century. Matter was a transitory phenomenon—the essential constituents of the universe, the "elements," were earth, fire, air, and water. And if matter was capable of unlimited transmutations, as it appeared to be, it was clearly possible to make out of any given substance any other substance even the most desirable, namely gold. Here was an object of research so promising that it overshadowed all others. It was impossible to think of alchemy, or chemistry, as we now call it, without bearing the possibility of this great discovery in mind. Pure chemistry is a growth of the last hundred and fifty years.

We are apt to smile at the delusions of the alchemist. His expectation that at any moment he might find gold in his crucible seems to us a "fixed idea." But what other motive had he for research? Merely to mix things together, to heat them and cool them, to sublime and condense, to dissolve in water or alcohol in order that he might see what happened, was to play the child. Anything might happen. The result might be pretty or ugly, pleasant to smell, or the reverse; but it could not be useful. What purpose was served when, at the end of a long succession of processes, his chemicals disappeared into thin air, with an unseemly haste perhaps which smashed his retorts, and laid the philosopher upon his back? Nothing is more difficult than to transport oneself back into a former age, without carrying thither the mental preoccupations of the age in which one lives. Had we lived at the beginning of the last century what discoveries we should have made! No doubt. But what principle would have guided our researches before the permanence and irreducibility of the elements, as we now know them, was established? To pass matter through one form after another was futile, unless it had a practical

object; whereas to combine elements of known valency is to work out a problem in solid mathematics. It can be done on paper before it is done in the laboratory.

Another object for chemical research presented itself to the natural philosopher, who was also a physician, as the most legitimate outcome of the theories of his day. The human body, which seemed to be a properly constructed machine with an innate tendency towards health, was nevertheless constantly deviating towards dyspepsies, rheums and fevers. What cause for these aberrations could there be save something wanting in its chemical constitution? The alchemists gave place to the iatro-chemists, whose quest was not gold but the elixir vitæ.

Scientific Method.—A "control-experiment" is the compass of science. As the mariner checks the course of his ship by comparing it with the magnetic meridian, so the man of science estimates the bearings of his observations by comparing them with the negative position—the zero-line from which they diverge. It may be easy to devise a control-experiment, or it may be the crux of the problem. When a farmer is persuaded by the agent for a manure company that "there is nothing like kainit for clover," he scatters it broadcast over his fields and then, as the crop grows, asserts that it is heavier or not heavier than it would have been had no kainit been used. Probably his judgment varies according as he is a "go-a-head man" or "one of the old school who doesn't hold with artificials." The scientific agriculturist, on the other hand, divides his fields into sections, and sets aside in each a control-plot on to which no manure is cast. The weight of clover obtained from the "control" is compared with the weight obtained from the manured ground. The cost of the manure is deducted from the increment in value of the crop, and the difference is the profit which accrues from the use of the manure. So far no difficulty in checking results has been experienced. But how is he to tell what the result would have been had the season been wet instead of dry, or dry



FRANCIS BACON, LORD VERULAM.

1561-1626.

instead of wet; had there been less reserve of nitrogen in the soil or more phosphate? Or again, how is he to tell whether kainit is equally useful for light soils and heavy, for gravels and marls and clays? It is not the experiment which costs trouble but the control. Anyone can say try x, or y, or z; it is only the trained experimenter who can say whether, and how far, the result is due to the use of x, or y, or z.

If, on the map of a certain county—we are citing an observation recently brought to our notice—the extent to which cancer is prevalent is marked by shades of grey, the "cancer spots" are sufficiently dark to attract anyone's attention. Such a map having been made, coincident conditions were sought for, and it was observed that, within a certain area, wherever these foci of the disease occur a particular kind of tree (we will not say what tree, lest someone unversed in scientific method wage a crusade against it) is abundant and grows near the houses. Is there a similar connection between this tree and cancer? Long before the life history of "rust" had been worked out, farmers held a conviction — it was regarded as a vulgar prejudice—that their wheat was affected with rust in fields bounded by hedges in which the common barberry grew. It has since been ascertained that the fungus which in one stage of its existence affects wheat with rust, is in another stage the aecidium or cluster-cup fungus of barberry; and it has been found, not only that rust occurs where there are barberries, but that it does not occur to the same extent where there are none. The illustration is not altogether satisfactory, for rust occurs in generation after generation of wheat-plants in Australia and India, where the barberry is not found; but this fact does not disprove Du Bary's assertion that in England its choice of host-plants alternates between wheat and barberry. It shows either that rust can dispense for a long period with the aecidium-stage, and that its spores lying hid in the grains of corn germinate when the wheat germinates and infect

the new wheat-plant with the fungus; or else that in Australia and India rust finds other hosts which serve its purpose equally well. There are difficulties still to be cleared up regarding the mode of infection of the corn. If our subject were the botany of parasitic fungi we should have to look further into this matter, but as an illustration of the relation which has been supposed to exist between the germs of cancer in Man and their life in a vegetable host the analogy is sufficiently complete. Can we say of cancer that it does not occur where the suspected tree is absent? On the contrary, cancer is found in coral islands where the cocoa-palm is the only tree, and on the plains of North America, where no tree raises its trunk for more than a thousand miles. In other districts in England other conditions have been found associated with great prevalence of cancer; but as yet none have stood the test of the control-experiment. At present, therefore, the concurrence of the tree and cancer, like the concurrence of various other conditions and this fell disease, must be looked upon as a coincidence.

The control-observation is the key to the position. Paradoxical as it sounds, the ingenuity of the man of science is taxed not in making observations and devising experiments, but in planning how to unmake them. The real difficulty is not experienced in imagining a possible cause for a known effect, but in devising an observation in which the supposed predisposing condition is absent, while all other conditions remain the same. The animal-magnetizers of fifty years ago asserted that their subjects were attracted by certain metals and repelled by others. Braid, to whose scientific investigation of the phenomena of hypnotism we owe the dissipation of numerous errors, when attending one of their séances, asserted with the same confidence, in the presence of the hypnotised person, that he would clutch at a round thing and shrink from a pointed one. When he offered him the only convenient object which he had at hand, his latch-key, his prediction was verified. Inverting the order of his pre-

diction on another occasion, it was still verified. The cause of the subject's movements lay not in the thing presented, but in the authoritative suggestion that he would behave towards it in a certain way. Countless claims made by mesmerizers and spiritualistic and theosophical miracle-workers of all grades would fall to the ground if their audiences understood how to devise control-experiments. We have a vivid recollection of the discomfiture of a certain "professor" whose subject could read the Lord's Prayer from a microscopic photograph, could obey the injunctions of his hypnotist when in a separate room, and do many other marvellous things, when a small scientific committee eliminated the possibility of suggestion. The droll feature of the performance was the surprise of the "professor," who had deceived himself. He had taken for granted that the effects were caused by the conditions of which he made parade, and not by other conditions which he had overlooked.

Scientific men are incessantly engaged in testing hypotheses by eliminating the condition which, *ex hypothesi*, is supposed to be the cause of phenomena. Science marches by observing, by colligating observations, by speculating as to the common cause which results in the similarity of the phenomena observed. We often speak of the ingenuity of an hypothesis, but truly this is almost equivalent to asserting its falsity or its unnecessary complication and want of finality, if it be not false. The progress of theory is towards unification, and therefore towards simplicity. When, in 1859, Darwin published his doctrine of Natural Selection, although he saw that only the fittest can survive, and that the struggle for existence must inevitably eliminate the unfit, he did not realise that this simple theory would suffice to explain all the adaptations to their environment presented by all living things. The eyes in a peacock's tail appeared to Darwin too elaborate to be merely useful; they seemed to possess a quality in excess of utility, a quality which affects us with a pleasurable emotion, and which we therefore term beauty. Why should not the pea-hen be susceptible to the same emo-

tion? It might be that the brilliant colouring or bizarre marking of the male was useful to the female at the breeding season, because it made her mate more conspicuous, and so diverted the enemy's attention from her, or it made him more terrifying and therefore more useful as her protector, but still in selecting her mate she would choose the one which in her eyes was the more beautiful—does not the peacock take endless pains to display his charms?—and thus the decorations which were in excess of utility would be perpetuated and still further developed, owing to the possession by the female of this sentiment of beauty which is, as it were, an exaggeration of the sense of utility. Therefore Darwin complicated his theory with the doctrine of Sexual Selection. Control-observations, by eliminating this supposed cause—the female's æsthetic preference—have shown that the doctrine of Natural Selection does not need qualification. Nature destroys the less fit. In peacocks, fitness is proportional to gorgeousness.

One more illustration of a control-observation of an entirely different class. Usually when a group of natural phenomena are observed, and an explanation of the feature which they present in common is formulated, the theorist asks himself, "Can I find the same result in the absence of any supposed cause? Can I find the same cause at work without the same result ensuing?" Then he arranges his conditions artificially —makes an experiment that is to say—and obtains a certain result. The next step is to omit the condition which he believes to be the cause of the result, and to see if the result is the same. Sometimes, on the other hand, it is not the facts that he needs to test, but his own attitude of mind towards the facts. It is not uncommon to hear the remark, even in semi-cultured society, "The moon changes to-night, we shall have a change in weather." "How often does your moon change, dear madam?" asks the man of science. "Once a week of course." "Well, you see I have adopted the metric system. My moon changes ten times in a month, and therefore as this is just the end of

the first week my weather can't change for at least another day."

How are we to know that phenomena which appear to be alike are alike in quality, and not merely alike in appearance, or, in other words, how can we tell that the fact that they are alike indicates that their likeness is due to the same cause? Fifteen years ago, when Dr Gaskell announced his theory of the origin of Vertebrates from a crustacean-like ancestor, with the amazing inferences as to changes in the functions of organs which such a hypothesis implies, I happened to visit one of the most eminent of living zoologists, to whom I expounded the evidence upon which the theory was based. "Gaskell has a fiendish ingenuity in collecting coincidences," was the professor's comment. But what higher praise can be bestowed upon any observer? It is his business to collect coincidences, and then to postulate the cause which determines that the observed phenomena coincide. When he has found this, he is in a position to formulate a "law." Yet anyone who pays attention to this matter will learn that it is very dangerous to conclude that because things coincide therefore they have a common cause. It is mathematically expressed in the Law of Chance, and yet in everyone's experience there has happened at some time or other so startling a coincidence that no Law of Chance seems adequate to account for it. Here is one which could hardly be devised in the fertile brain of a Sherlock Holmes. The present President of the Royal College of Surgeons of Edinburgh told the writer that some time ago a woman was brought into his ward in the Infirmary at Edinburgh shot through the head by a bullet from a revolver which someone was examining in a sale-room. She died. Nine years afterwards a woman was brought into his ward shot in the chest by a bullet from a revolver which her husband had bought in a sale-room. She recovered, but a judicial enquiry was held. Some days after the enquiry the chief of police entered Dr Chiene's consulting-room, and producing a revolver said, "I have something here that will interest

you. You said at the inquest that it was a very remarkable coincidence that you should twice have had in your ward a person shot in such an unlikely way. I have looked up the old case, and I find that this pistol which recently wounded a woman is the same one which killed your patient of nine years ago." Anyone with a touch of superstition would be likely to remark that, until that pistol has been dropped into the deepest hole in the Pacific Ocean, it is not safe to enter a sale-room!

From the infinite sum of our fancies and illusions particular instances are picked out upon which are based marvellous tales of telepathic communication and premonition in dreams. If they were not marvellous they would not be remembered, and if their marvellousness hardly merits the telling, a tendency is innate in most narrators to bring it up to the effective standard. Such stories as have been published are conspicuously wanting in the only kind of support which would give them value as evidence—documentary corroboration. Does any residuum which cannot be explained, without the inference of the existence of "psychic force," remain over after coincidence and unconscious and conscious lying have been allowed for? The margin of evidence is strangely narrow.

Has science a method proper to itself? Induction and deduction are terms which sound antithetical. They have been the watchwords of opposing forces in many a battle. For more than a century thinking Europe was divided into Baconians and Cartesians. Francis Bacon laid down the laws of scientific evidence in his *novum organum* with much the same pedantry as he would have displayed in regulating judicial procedure. "He talks as a Lord Chancellor," said Hobbes. According to Lord Chancellor Verulam, Science must progress from step to step, never committing itself to any hypothesis which is not the necessary inference from observation. The true scientific method is always to be strictly inductive—a most useful restriction, and especially necessary in Bacon's day.

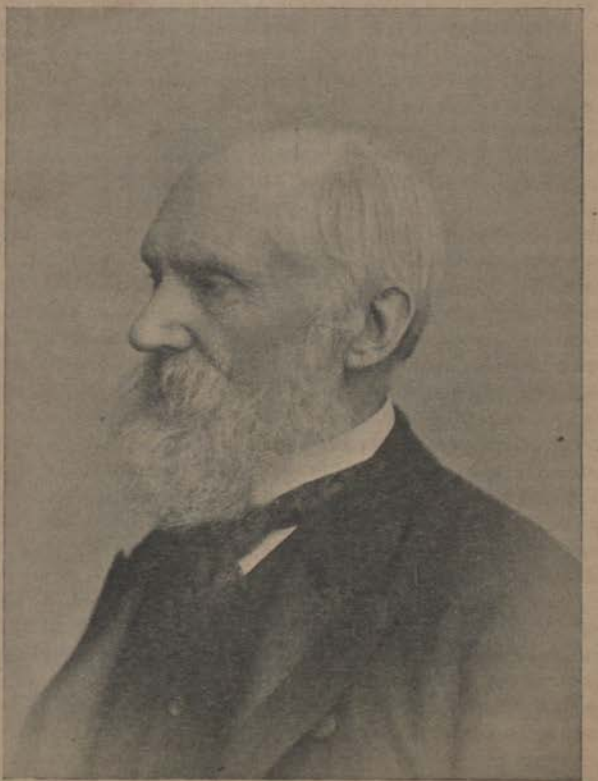
Descartes' richer imagination took longer flights. In certain matters he even asked of his inner consciousness how he himself felt that things ought to be? How would he have made them had he had the making of the world? Then he collected evidence to show that they are as he supposed *à priori* that they would be. This is deduction; building downwards, although the process by which Descartes tested his evidence was as strictly inductive as Bacon could exact.

After all, the difference between induction and deduction is a question of name. We know nothing of the universe but that which we have learnt by experience or that which our predecessors have learnt by experience and have recorded for us. When the imagination takes a long flight, when it seeks an *à priori* explanation it is but appealing to experience, although it is unable to trace the steps along which the reason marches in seeking so distant a cause for effects which are near at hand. And when we come back to experience for proof of the applicability of far-fetched explanations the reason moves towards it by processes of induction. Every hypothesis is by definition an advance on knowledge. It is in the nature of a deduction that reason goes on before observation. Observations are then built up to support reason. The difference between induction and deduction is but a difference in degree.

It is characteristic of science to proceed with the utmost caution, to build a pyramid of inductions, each tier of which contains a smaller number of generalizations than the tier upon which it rests, until the apex is a comprehensive generalization which unifies all below it. Speculation is the scaffolding or system of guiding-lines of this edifice. As facts are packed beneath it the apex of the scaffolding has to be shifted, raised, lowered, until at last it is properly centred. Then the whole is so compact that no fact can be detached.

Darwin abolished the distinction between induction and deduction in science. His hypothesis was of so general a

character that it embraced every manifestation of life; it gave a reason for the form and functions of every organ of every living thing. The history of philosophy cannot give an instance of a wider generalization and yet the proofs of Darwin's hypothesis, which far outstretched Descartes' most imaginative deduction, are as rigidly inductive as Bacon could desire.



LORD KELVIN, *late P.R.S*

SECTION II

CHAPTER I

The Age of the Earth

Few subjects of research and speculation are more interesting than this. An attempt to ascertain the age of the earth, or rather to ascertain the length of time during which the earth has been such as we now know it—a solid globe capable of supporting life—brings us face to face with far-reaching questions which cannot fail to impress the imagination. Although the solution of these questions will never influence the use which each individual makes of his own life, they nevertheless appear to be of fundamental importance to every one who seeks to bring the universe within his mental grasp. The attempt to give a general idea of the data which are available will afford us the opportunity of illustrating the methods adopted by astronomers, physicists, geologists, and biologists in grappling with this problem.

How long have the conditions upon the surface of the earth been such as to render Life possible? By life we mean the existence of such organisms as now surround us—organisms which depend upon the possession of a nitrogenous compound, protoplasm, for the chemical changes by which the phenomena of living are exhibited; and upon the presence in the atmosphere, or dissolved in water, of the element oxygen with which their nitrogenous constituents may combine. We cannot imagine any other kind of life. If, when we ask the inevitable question, "Is this the only planet upon which life is possible?" the astronomer or spectroscopist answers, "There is no other in which protoplasm

would remain a compound, or in which it would find itself in the presence of oxygen"; then it is idle to speculate as to whether life is possible elsewhere than on the earth. If Venus does not rotate upon her axis, but always turns one face to the sun and the other to the outer cold, there is no life on Venus. If Mars is too cold for protoplasmic metabolism, or if, as Dr Johnstone Stoney calculates, the force of gravity on this planet is too small to prevent water-vapour from escaping into space, then there is no life on Mars. Speculation as to the possible existence of different orders of living things, of beings which do not contain nitrogen or exhibit life by combining with oxygen, ranges beyond the domain of science. There have not been wanting thinkers who assert that they can imagine beings in whose constitution silicon plays the same part which nitrogen plays in ours; living things with the same constitution as china dolls. Fancy may play at speculation in this way. It may surround its new creation with an atmosphere of iodine, and feed its inhabitants upon carbonate of lime. They may suffer calcareous pains and give way to siliceous emotions. But this is not Science. Speculation has lost touch with experience.

Living things require certain strictly limited conditions of existence. Plants cannot fix carbon from the atmosphere unless the temperature be somewhat above the freezing point, and somewhat less than half-way to the boiling point of water; and animal life depends upon the pre-existence of plants. The question is therefore narrowed down to this: For how long has the temperature of the earth been fixed within these limits, other conditions such as the force of gravitation and the receipt of light from the sun being the same as at present? Sunshine and shower, day and night, moderate heat and moderate cold were as necessary to the first inhabitants of the globe as they are to the plants and animals which live upon it now.

The answer to this question hardly comes within the province of the astronomers. Yet they were the first to

show that there is evidence of such a change in the movements of the earth as must when traced backwards bring us at last to a far limit for its inhabitableness. Astronomical observations prove that the rapidity with which the earth rotates has sensibly diminished within historic times. Laplace showed that the relative velocity of the rotation of the earth and of the orbit of the moon have changed. The hour of commencement of eclipses of the moon (the time, that is to say, after the moon had risen before the eclipse commenced) and of their duration have been recorded with accuracy ever since they were noted by the astronomers of Babylon twenty-seven centuries ago, and from these records it is clear that either the rate at which the moon travels has increased or the rapidity of the earth's rotation has steadily diminished. Laplace considered that the moon has hurried while the earth has kept time, and he pointed out a certain cause (the progressive diminution of the eccentricity of the earth's orbit) which must produce an acceleration of the moon's motion; but Adams, after estimating the utmost effect of this accelerating cause found that it can only account for one half of the discrepancy in time between the moon and the earth. It is indisputably true that the earth is losing its velocity of rotation. It is twenty-two seconds later at the end of every century. Every day is longer by the fraction of a second than the corresponding day of the year before.

For this loss of time on the earth's part the moon is chiefly responsible, since the attraction of the moon is the main factor in producing tides, and the slowing of the earth is due to the friction of its envelope of water. As the earth rotates it tends to leave its envelopes of water and air behind it, because the attraction of the moon and the sun keep, as it were, a hold upon them. The heaping up of the tide is not merely a rising of the water towards the moon, but the wave is drawn backwards with regard to the movement of the earth. Now, wherever there is movement of matter upon matter, whether the substances rubbed against one another be

solid, liquid, or gaseous, energy is liberated. This energy takes the form of heat, which is dissipated into space, unless there be some countervailing conditions which restore the heat to the body losing it. The friction of the tidal wave upon the surface of the earth diminishes the energy of the earth's rotation in exactly the same manner as a brake diminishes the energy of rotation of a wheel. In point of fact the moon puts a continuous brake upon the earth.

There is therefore no reason to call in question the accuracy of the records of eclipses of the moon. They supply historical evidence that the earth rotated more rapidly in former times than it does now. If we had no such records we should still be able to prove that the friction of the tides must have produced a slowing effect.

The evidence as to the actual rate of rotation can be put to a most important use. We know that once this earth was so hot that it was molten. Now, when a fluid sphere is made to rotate, centrifugal force causes its equator to increase, while its polar diameter is diminished, and the extent to which it assumes the form of a disc with a rounded edge (an oblate spheroid) depends upon the amount of the centrifugal force, *i.e.* upon the velocity of its rotation. The earth, as we know it, is almost perfectly rigid. We still speak of the "crust of the earth" as if its surface only were solid and its contents molten, but this theory has been abandoned. Physicists hold now that the earth is solid to its core, except for patches of molten lava. At any rate it is so nearly rigid that any deformation by centrifugal force, or return towards sphericity owing to the diminution of centrifugal force, is out of the question. The earth has the shape which it assumed when it first became cool enough to solidify. It is, as we have said, an oblate spheroid, but the difference in length between the axis joining the poles and the axis passing from one side of the equator to the other is much smaller than the contemplation of most models of the globe

would lead one to suppose. The equatorial axis is only seventeen miles longer than the polar axis. Therefore it cannot have been spinning much faster when it first became solid than it does now. Lord Kelvin estimates that the centrifugal force at the time of solidification cannot have been more than 3 per cent. greater than it is at present, and therefore, having regard to the known rate of retardation of the earth's rotation, this event occurred not more than 100 million years ago.

Another line of argument which leads to much the same result depends upon the evidence that the earth is losing heat. The craters of extinct volcanoes, scattered over all parts of the globe, testify to the existence of much greater plutonic activity in former times than is anywhere exhibited now. The sixty or more cones which may be seen from the top of Mount Eden in the neighbourhood of Auckland, New Zealand, give to the landscape the appearance which the surface of the moon would present were it clothed in green; and the almost perfect preservation of the cups of Mount Eden itself and of some of the surrounding volcanoes shows that it cannot be very long, in geological time, since they were in action. The subsidence of volcanic activity proves that there is less heat than formerly beneath the surface of the earth.

Again it can be shown that the nature of the record, preserved in this case by the rocks, might have been anticipated by a process of reasoning. It has long been known that the heat of the earth is greater at the bottom of a mine than it is near the surface. Observations made in many regions show that, after a level down to which the temperature is affected by the heat of summer and the cold of winter—a depth of a few feet only in England—the temperature steadily rises to the extent of 1° F. for every 50 or 60 feet. This proves that the more superficial strata are losing heat which they receive by conduction from strata placed more deeply. The earth is shedding heat into space. Lord Kelvin has calculated the amount of heat which is dissipated yearly, and has estimated

the time which has elapsed since the surface of the earth was so hot that all water upon it must have been in the form of steam. This, he says, was the condition of the globe less than 100 million years ago.

Lastly, the physicist attacks the problem from quite a different side. Having determined the outside limit of the age of the earth, he turns to the sun and asks, How old is that? How long has the sun been pouring forth the force which keeps plants and animals alive? What is the source of his energy? It cannot come from the same source from which we commonly obtain it, combustion. Had the whole sun been made of coal with an infinite atmosphere of oxygen in which to burn, it would have gone out in a few thousand years. When this fact was recognised it was suggested that the great mass of the sun might attract meteors, fragments of broken-up worlds, which would rush towards it with such velocity as to set free, when they struck it, the energy which the sun disperses as heat. But for the supply of the sun's heat in this way meteors equal in size, in the aggregate, to the moon would need to be sacrificed every year, and astronomy proves that space is not pervaded by such a multitude of shooting stars. It is now agreed that the heat of the sun is produced by the collision of the particles of matter of which it is itself composed. These collisions are brought about by the shrinking of the sun, which is losing four miles in diameter every century. To the question, How long has the emission of heat by this process been going on? Lord Kelvin answers: "The sun may have already illuminated the earth for as many as 100 million years, but it is almost certain that he has not illuminated the earth for 500 millions of years."

Thus the physicists have approached the problem from several sides, and drawing the mesh tighter and tighter have shown, not how long the earth has been capable of supporting life, but what is the limit beyond which it is certain that it was not so constituted. Lord Kelvin is of opinion that this limit does not exceed 20 million years. Physical methods involve

long calculations, and the indisputable accuracy of mathematics gives to the results an appearance of rigid exactitude which may be misleading. It is however obvious that mathematics cannot produce an accurate result unless the data be accurate, and if there be any uncertainty in the conclusions just formulated, it must be due to errors in the data upon which they are based. Each of the estimates starts with certain assumptions. We are very far from calling these in question, but if any person is ever found competent to act as umpire between the physicists and the geologists (who, as we shall show directly, prove a longer period than 20 millions of years), he will inquire first whether these assumptions are justified. Is the time-change assigned in right proportions to the moon and the earth respectively? Is it true that the shape of the earth has not altered since it cooled to the point of solidification? Do the figures which represent the increasing heat of the earth, from without inwards, hold good for all latitudes, and are they independent of local causes, such as the proximity of mountains, etc.?

Geologists approach the problem from the opposite side. They ask the direct question, How long has it taken to deposit all the fossil-bearing strata, and the earlier sedimentary rocks which were capable of supporting life, although no fossils are preserved in them? Sir Archibald Geikie answers that it must have taken more than 20 million years. These strata attain in the aggregate to a thickness of 100,000 feet. The chalk alone reaches to a thickness of 10,000 feet in certain of the western districts of the Rocky Mountains, and chalk is a deposit which could be formed but very slowly at any period of the earth's history, seeing that it is made up of the shells of microscopic animals which obtain the carbonate of lime for their manufacture from the sea. But, neglecting all details, and looking at the matter from the broadest point of view, Geikie endeavours to ascertain the rate at

which the materials which form rocks are deposited; for, since all these materials are borne down to the sea by rivers, we can calculate, if we know the amount which any river carries down in a year, the depth to which it will cover a given area of the bottom of the sea. Measurements which have been made show that rivers deposit from $\frac{1}{760}$ to $\frac{1}{7000}$ of a foot in a year, over an area equal to the area from which they obtained the mud, sand, and gravel which they wash into the sea. The limits between which the amount of deposit varies are necessarily wide, because the activity of the process of denudation of the land varies so greatly. Mountains are worn down more rapidly than plains, and where the rain-fall is heavy, or the splitting action of frost comes into play, denudation is much more rapid than in dry, warm places. Supposing the area of sea to have been always equal to the area of land, and the rivers to be the only carriers of deposits, it is clear that it would take from 70 to 700 millions of years to lay down strata 100,000 feet in thickness. These figures are interesting as guiding lines of thought, but it is obvious that corrections must be made for the carrying power of the wind, which robs the rivers of much of the dust and sand which would otherwise find their way into their streams, and for the eroding action of the sea itself. Nor is it certain that the aggregate thickness of the strata would amount to 100,000 feet if it could be measured in any one given place. Sir Archibald Geikie says that "on a reasonable computation these stratified masses, where most fully developed, attain a united thickness of not less than 100,000 feet." But it is unlikely that all could have been fully developed in any one place, since at no time was the same deposition occurring all over the globe. Where one kind of rock was formed for a very long period in one place, so that it attained to great thickness, the next succeeding stratum may in that particular place have been very thin.

And again, as pointed out by Mr Wallace,[1] although the denudation of the land by the agency of rain extends over very large areas, the rivers deposit all the silt which they carry down to the sea within 150 miles from the coast, and even this limit is reached only opposite to the mouths of large rivers. It is, therefore, necessary for the purposes of calculation that an estimate should be made of the average thickness of the sedimentary rocks all over the globe, beneath the bottom of the oceans as well as over existing continents. Until this has been done, and at present it seems to be an impossible task, the geological figures are of comparatively little value.

To biologists this controversy is of great interest, although they cannot be said to have any claim to an independent opinion, since they have absolutely no standard by which to gauge evolutionary time. Although plants and animals have been changed profoundly by cultivation and breeding within historic times, there is no evidence that they have changed within the historic period without Man's interference. It is impossible to prove that the hands of the evolutionary clock have moved. Such negative evidence is of value, however, as showing that if evolution proceeds so slowly that it cannot be detected in the process, even though its records extend over several thousands of years, it must have required a long period to allow of the changes in the forms of living things which are pictured in the fossil-bearing rocks. When Charles Darwin was submitting to the world his doctrine of the Origin of Species, he felt it necessary to insist, "how incomprehensibly vast have been the past periods of time," because he foresaw that the objection would inevitably be raised that the world had not existed long enough to allow of the origin of all living forms by evolution. But although, to put it briefly, the biologist wants as much time as he can get, he has not the least idea as to how much would suffice.

[1] "Island Life," chap. x.

An interesting side issue has recently been raised. An eminent zoologist has expressed the opinion that evolution in early times and among primitive forms proceeded more rapidly than it has done since. Evidence bearing upon this view is likely to be sought for eagerly during the next few years. At first sight it appears more likely that the change in the rapidity of evolution has been in the opposite direction; that as competition has become keener the extent of variation has increased. Among simple and comparatively uniform organisms favourable variations of very small extent would give great advantage to their possessors. As specialization increases, a variation is of little use unless it is pronounced. Just as, to reason from analogy, a new sign-board sufficed to bring business to a tradesman two centuries ago; whereas only the boldest advertisements attract attention at the present time. Again it cannot be supposed that all the surface of the globe became life-supporting at the same epoch. As the earth cooled, the regions in which living things could exist must have increased in area, and although, on account of the rapidity of their multiplication this extension of the life-carrying area may have counted for very little, it must, in some degree, have delayed the crisis of the struggle for existence. Uniformity of reproduction would seem to be the primitive law. It might be supposed that when the pendulum of variation first began to swing, its excursions were almost imperceptible and that their departures from zero have been steadily increasing ever since. Indeed the very tendency to vary is a favourable variation in itself which must have been increased by natural selection, since the race with the greatest potentiality of variation is the most likely to hold its own under changed conditions of existence. On the other hand, the rock-records seem to indicate either a diminishing range of variation, or an increasing rate of deposition. Either it took longer for the older strata to accumulate or the plants and animals which are fossilized in them changed from one

form into another with greater rapidity than in later periods of geological time. Again it might be urged that, as specialization increases, all the openings for new developments are filled up. With the present immense variety of forms it is almost impossible for a plant or an animal to discover an effective new departure.

THE HON. ROBERT BOYLE.

1627-1691.

CHAPTER II

The Ultimate Constitution of Matter

In chemistry more than in any other branch of Natural Science it is possible to draw a marked distinction between the work of the laboratory and the work of the study—between manipulation and philosophical thought. Two lines of research stretch to the chemist's mental horizon. He may either devote the chief part of his time to investigating the properties of substances, or he may reason as to the relation between substances and their properties, and devise experiments to check his hypotheses. He is in charge of the matter of the universe. It is his business, in the first place, to prepare all the substances which can exist in a pure, homogeneous, or isolated state, and to investigate their behaviour in relation to one another. He separates matter as it is found in nature into its elements. He forms every combination of the elements which under any conditions can exist as homogeneous bodies—as bodies, that is to say, the properties of which are invariable and uniform throughout their whole mass. That the substance with which he is dealing is partially or completely decomposed during many of his manipulations—that, for example, a salt when dissolved has not the same homogeneity which it exhibited in its crystalline form before he dropped it into the water—that it is partially resolved by the water into its "ions"—does not affect the final result, profoundly as it modifies the action of this salt upon other salts in the same solution. The chemist recognises that, when he is working with a substance in solution, his homogeneous or unit substance is not the salt with the properties of which he is conversant in its dry condition. The salt tends to divide into its ions.

It is the reactions of the separated ions that he is now investigating, not the reactions of the salt as a whole. But at the end of the reaction a new product comes back into the light, and he speaks of this as the product of the interaction of the salts which he dissolved and the other reagents which he used, whatever they may have been. He has therefore to resolve the mixed constituents of the globe into their elements, and to ascertain the properties of every combination of elements which can exist, whether these combinations are separable as forms of matter which can be isolated and set aside in the drawers and bottles of the laboratory, or whether they can exist as separate bodies only under conditions which render their isolation impossible.

But in chemistry, as in all other branches of Natural Science, the observation of phenomena provokes reflections as to their cause. Why do the elements combine? Why, when a compound has been formed, is it ready under certain circumstances to exchange one of its elements for another, or to react with some other compound in such a way as to produce either a more complicated compound, or two or more substances which do not resemble either of those from which they are derived? Chemical philosophy is occupied with many problems; but the one which is most distinctly chemical is the determination of the positions which the elements in a compound occupy relatively to one another, the architecture of derived substances, as it may be termed. It is necessary to think of matter as composed of atoms, whatever may be the nature of these units of structure. If our powers of vision were sufficiently increased, we should see matter, not as we see treacle, but as we see marbles when enclosed in a vase of clear transparent glass; with this difference that the marbles would not be in contact with one another, but separated by vacant space, and not at rest but in a state of perpetual motion. The intervals between the marbles (not the size of the marbles) would vary according as the matter was in a solid, liquid, or gaseous state. They would also be proportional to the amount of heat in the

body. The hotter the body the more rapidly its particles move; the more rapidly they move the greater are the intervals which separate them, or vice versa. But if our powers of vision were still further increased we should see that each marble is a group of smaller bodies, still not in contact but separated one from the other by very much smaller spaces than those which separate the marbles. In chemical language matter is composed of molecules and molecules of atoms. The chemist attributes the properties of matter to the arrangement of the atoms in its molecules. He believes that when he changes the nature of a substance —when he alters its properties, that is to say—he changes either the number or the kind of atoms, or their mutual arrangement in the molecule; for he has the best of reasons for thinking that a molecule does not consist of a certain number of elementary atoms arranged at haphazard, as stones of several kinds might be thrown into a sack, but that the atoms are put together according to a plan so definite, that no two atoms can change places in a molecule without an alteration in the properties of the substance.

There are certain substances, in number about seventy, which cannot be changed one into another. These are the chemical "elements." Until the seventeenth century all forms of matter were supposed to be transmutable. Aristotle taught that there is only one fundamental matter which is united in Nature with varying quantities of the four "elementary principles," earth, fire, air, water; and that the properties which different forms of matter present, depend upon the relative amounts of the several elementary principles impressed upon them. We may look upon this ancient doctrine (which had an oriental origin long before Aristotle's time) as a transcendental explanation of the Nature of Matter starting from physical data. The alchemists, substituting ideas which may be called chemical, little as they resemble the clear conceptions of modern chemistry, assigned the differences in property of the metals to their possessing the three "Chymical principles," salt, sulphur, and mer-

cury in varying degrees. Such notions seem to us to be wide of the mark; but if we try to imagine ourselves as living in the days before the principle of the Conservation of Matter was determined, we shall see that the permanence of Aristotle's elements could be assumed with a greater show of reason than the permanence of matter. The composition of the air was known no better than the composition of flame. A piece of wood when ignited was converted into flame save for a little residue of ash. Clearly it consisted of ash, or earth, and flame. Boyle founded modern chemistry when, in language free from ambiguity and mysticism, he enunciated the theory that there are certain indestructible substances which cannot be resolved into simpler constituents or transmuted one into the other. Such truly unchangeable substances are properly entitled to the name of "Elements."

Since they cannot be broken up into simpler bodies, the chemist accepts, provisionally, the doctrine that all the atoms which compose any given element are uniform in shape and size, and are in every other respect of the same kind. He is aware that certain elementary bodies, such as carbon, boron, phosphorus, exist in more than one modification or state, as diverse in properties as soot and diamond (two forms of carbon), but for purposes of calculation, he speaks of the atoms of each particular element as if they were truly unalterable, or at any rate truly indivisible. The language and formulæ of chemistry imply that every element has its own specific atom which differs in size, and therefore in all its properties, from the atoms of every other element. If it were possible for us to see the atoms, we could with a certain scale of relative sizes (atomic weights) say which atoms were those of phosphorus, which of silver, and so on.

Before, therefore, he studies the architecture of matter, the chemist examines the constructive materials which Nature uses. He finds that she builds with some seventy different elements. As we have already said, he recognises each of these various elements by the size of the atoms of which it is composed.

It has long been suspected that the chemical unit or atom is not, as its name implies, "an ideally indivisible portion of matter." On the contrary, it would seem that the *true* atom cannot under any conditions be made to act as a unit. Nature has arranged the true atoms into groups, which always act as groups, and each of which is therefore, for all practical purposes, an atom. We cannot break up the groups, and we can conceive them as divisible only in a universe quite different to the universe that we know.

According to this modern conception of the nature of matter, there is but one fundamental substance, protyle. This arch-element does not exist except in various states of condensation or groupings of particles held together by indissoluble bonds. The "atoms" of all the elements, even the lightest, hydrogen, are aggregations of protyle-atoms.

We owe this conception of an arch-element in various fixed degrees of condensation to Mendeléef's discovery that all the elements with which we are acquainted can be arranged in series according to the numerical value of their atomic weights. The chemist cannot estimate the weight of an atom, but he can determine the amount of any given element, which enters into combination, relatively to the amounts of the other elements with which it combines. Dalton (1802) pointed out that if all possible compounds of oxygen, hydrogen, chlorine, lead, etc., are made by the chemist, and then the compounds are isolated in a pure state and analysed, the superfluous substances which have not entered into combination being removed, it will be found that whatever the amount (relatively to any arbitrary standard) of the element utilised, in all the compound it will be either this amount, say x, or some simple multiple of this amount, say $2x$, $3x$, $4x$. For example, nitrogen which is a monovalent atom combines with oxygen to form the compound N_2O_5. With more nitrogen and less oxygen, the compounds N_2O_4, N_2O_3, NO, N_2O are formed; but there are no compounds of nitrogen and oxygen which contain a larger proportion of nitrogen than does the compound N_2O, or a larger proportion of oxygen

than N_2O_5. So simple are the multiples, that if the chemist, wishing to play at making compounds, cuts out blocks of wood and represents each of the elements by a block of a particular colour, he will never need more than six blocks of any given colour to build up all the compounds with which Dalton was acquainted. Since Dalton's time a small number of more complicated combinations, such as the complex silicates and phosphomolybdates, have been discovered, but his law still holds good for the vast majority of inorganic substances. This is the basis of the atomic theory. It makes it possible to denote the elements by symbols; O for oxygen, H for hydrogen, Fe for iron (ferrum) etc., and to express their combinations as OH_2, FeO, Fe_2O_3, Fe_3O_4, $Fe_2O_3H_2O$, etc.

If any arbitrary unit be chosen, if, for example, it be assumed that the weight of the atom of the lightest element, hydrogen, is 1, then it follows that in any compound in which there are exactly the same number of atoms of hydrogen as of some other element, the actual weight of the other element which enters into the compound is to the actual weight of the hydrogen, as the weight of the atom of the other element to the weight of the atom of hydrogen. For example, if we have reason to believe that hydrochloric-acid gas is formed by the union of hydrogen atoms and chlorine atoms in equal numbers, its formula may be expressed as HCl; and if, when it is analysed, this gas is found to contain by weight $35\frac{1}{2}$ times as much chlorine as hydrogen, the atom of chlorine weighs $35\frac{1}{2}$ in the hydrogen scale.

We may digress for a moment to explain how it comes to be possible to ascertain whether the same number of atoms of two elements are in combination, or unequal numbers. Cavendish found that when he filled a globe with a mixture of pure hydrogen and pure oxygen in the proportion of 2 cubic inches of hydrogen for every 1 cubic inch of oxygen, and exploded the mixture, nothing remained but water. Except for the water-vapour the globe was empty. It could be refilled with the same mixture over and over again, and yet after several explosions nothing remained in it but water.

Gay-Lussac and Humboldt (1805) repeated this experiment, not only with hydrogen and oxygen, but with hydrogen and chlorine, and various other gases which combine to form gaseous products, and they found that the volumes of any two gases which must be used if a compound is to be formed and no remainder left over, bear such simple numerical relations one to another, as 1 : 1, 2 : 1, 3 : 4, etc. This discovery, considered in its bearing upon Dalton's observation that the proportions by weight in which any given element enters into the formation of several distinct compounds, bear very simple numerical relations one to another, led to the formulation by Berzelius of the theorem that equal volumes of gases contain equal numbers of atoms. Berzelius' generalization was fallacious, because he did not know that even in the gaseous elements the atoms are not isolated but combined into molecules. When Avogadro substituted the word molecule for atom, and said that "equal volumes of all gases contain equal numbers of molecules," the theorem assumed an expression which is subject to no dispute. No matter what gas is put into a given space, or what its weight, the gas is always composed of a certain fixed (though not ascertained) number of molecules, provided the pressure and temperature are constant. Therefore one gas is heavy and another light, because in the one the molecules are large, in the other small. A gas is a gas (and not a solid or a liquid) because its molecules repel one another. When pressure is put upon a gas its molecules are squeezed nearer together, and the amount by which they are approximated varies directly as the amount of pressure. Again, when a gas is heated the mutual repulsion of the molecules is increased, and the force of repulsion is exactly proportional to the temperature. When air is heated from 0° C. to 1° C. it expands by $\frac{1}{273}$ of its volume, and if it be heated from 95° C. to 96° C., its volume is increased by exactly the same amount. But owing to the fact that the atoms of some gases are heavy, while those of other gases are light, it takes more heat to raise the temperature of the former than of the latter. If it

were desired to raise the temperature of two gases 1°, a spirit lamp would need to be kept just as much longer under a vessel filled with the gas made of heavy atoms than under the gas made of light atoms, as the atoms were heavier in the one case than in the other. In other words, the atomic weight of a gas divided by its specific heat gives a constant number as dividend. All lines of evidence converge to support the modern view that matter, in a gaseous state, consists of separate molecules, or groups of atoms, which are at the same distance apart in all gases under the same conditions of temperature and pressure; and therefore that the weight of a gas depends, not upon the number of molecules which it contains, but upon the weight of each molecule. From this it follows that there can be no uncertainty as to the molecular weight of any element if it can be examined in the gaseous state. It is directly proportional, both to its specific gravity and to its specific heat. The molecule of every element when in a gaseous state, is a group of two atoms; with the exception of the gas, argon, which Lord Raleigh and Professor Ramsay have recently discovered in the atmosphere, which is monatomic, and sodium and potassium (and probably certain other elements), which become monatomic at high temperature. In the cases of elements which cannot be converted into gas, the molecular weight must of course be determined by indirect methods.

A study of the numerical relations between the atomic weights of the elements led Mendeléef to the greatest generalization of Modern Chemistry — the formulation of the "Periodic Law." This generalization more than any other has given rise to speculation as to the ultimate constitution of matter. It seems to be a logical inference from the periodic relations between them, that the atoms of all chemical elements are really clusters of atoms of the fundamental substance, protyle. If this be true, the indestructibility and immutability of an element means the indivisibility by chemical means of the protyle-cluster. Neglecting all qualifications, the Periodic Law may be explained as follows—

Mendeléef's Law (1869).—The atomic weights of the elements (on the hydrogen scale), range from hydrogen 1 to uranium 240. They might therefore be arranged in a linear series. But a consideration of their properties shows that the elements fall into groups. If any property common to all elements be considered, and a band, varying in width according to the degree in which they severally exhibit this property, be drawn down the full length of the list, it will be found that prominences and subsidences occur at intervals on the band. No matter whether we are comparing the elements with regard to the melting points and boiling points of certain of their compounds, the heat evolved during their union with chlorine, their spectra, the colours of certain of their salts, their magnetic properties, or their occurrence in Nature, we find that the line representing the quality of the character or the amount of its development undulates down the list. And the importance of this comparison becomes apparent when it is noticed that the periods of maximum and minimum prominence of all these different characters approximately coincide.

To take an illustration from acoustics: each tone of the diatonic scale has its own rate of vibration, but each tone is not a separate thing unrelated to all other tones. Some can be sounded in harmony, others cannot. So also the gamut of the elements may be divided into groups which strangely resemble octaves. Perhaps this analogy which has attracted the attention of many chemical philosophers is more than superficial; for the properties of the elements also depend upon the vibration periods of their molecules.

The observation that the properties of the elements, as well as those of their compounds, are periodic functions of the atomic weights of the elements—that the properties of the elements are determined by their atomic weights, that is to say—led Mendeléef to classify them as follows:—He ruled a sheet of paper into eight vertical and twelve horizontal columns. In the ninety-six places thus provided he disposed the elements according to their atomic weights, the lightest being

in the top left-hand square, the heaviest in the bottom right-hand square. The eight vertical columns he termed "groups," the twelve horizontal columns "series." The reader must not, however, think that this arrangement could be carried out on any simple arithmetical basis. There were, and still are, many difficulties and reasons for uncertainty. For example—

(1) The eighth element in each alternate series exhibits properties, which would equally justify its inclusion as the first of the next. It is therefore duplicated, and appears in both.

(2) Certain metals so closely resemble the duplicated members, that they have to be included with them in the eighth column. Thus iron, nickel, and cobalt, appear in the same square as copper.

(3) Hydrogen and helium (At. W. 4), the gas recently discovered by Professor Ramsay, stand alone in the first series, no other member of this series being known.

(4) There were several gaps in the table, of which some have since been filled up.

(5) The differences between the atomic weights of the several members of each series or of each group are only approximately constant.

Despite its want of arithmetical rigidity there can be no doubt but that Mendeléef's classification is based upon natural laws. The elements which he arranged in groups resemble each other in properties, their differences are differences in degree. The elements in the series differ from one another in properties, and the amount of their differences increases progressively from the first to the seventh or eighth member. Their properties therefore vary in kind.

Take as an example of properties the tendency to form oxides. Most of the elements form more than one oxide, but for each of them there is one oxide which chemists regard as characteristic. If R stands for any element, the characteristic oxide of group I. is R_2O; of II., R_2O_2; of VII., R_2O_7.

If we compare the hydrogen-holding power of the elements with their oxygen-holding power, we find that their capacities in this respect are reversed. The hydrides of group VII have the formula RH; of VI., RH_2; of V., RH_3; and of IV., RH_4. The justification of the octave arrangement is shown very clearly by these two sets of compounds. No single atom of any element can, so far as is known, combine with more than four atoms of oxygen, or with more than four atoms of hydrogen; but if its maximum hydrogen-holding power and its maximum oxygen-holding power are considered together, it is found that the number of atoms of hydrogen which it can hold, *plus* twice the number of atoms of oxygen (because O is divalent), always equals 8. To take illustrations from each of the groups IV., V., VI., VII., we find that carbon forms CH_4 and CO_2, nitrogen NH_3 and N_2O_5, sulphur SO_3 and SH_2, and iodine I_2O_7 and IH.

As yet the expression of the Periodic Law is tentative and provisional. The fact that it explains many hitherto inexplicable phenomena indicates that, when it is completely and justly formulated, it will account for many more. It exemplifies the grand function of science, to marshal the apparently unrelated and unco-ordinated facts of the universe. Boyle's rabble of elements is already a disciplined army. The discovery of the "periodicity" of their properties has given the chemist an entirely new grasp of the elements. As a mere *memoria technica* Mendeléef's table is of immense value to the student. When he thinks of an element, he no longer thinks of it as an isolated unit with properties peculiar to itself. Its place in the table shows him what its characters must be, relatively, both to the horizontal series and to the vertical group to which it belongs. But the Periodic Law, although we do not yet know its full meaning, is far more than an aid to the memory. It is prophetic as well as retrospective or explanatory. It has called attention to many of the shortcomings of chemical science, and foretold how they may be corrected.

The incorrect atomic weights of elements which would not fit into the scheme have been set right. The existence of vacant spaces in the table has led to the search for new elements; it has indicated their alliances, pointed to the minerals in which they might be looked for, and thus led to their discovery. Compounds which were supposed not to exist have been formed, after the position of an element in a group which usually yields such compounds has been admitted.

If Mendeléef's theory is correct, it follows that the number of elements is strictly limited. Some of them have not yet been discovered, but Mendeléef's prophecy that the vacant spaces will be gradually filled has already been verified in certain cases. New elements have been found which have the atomic weight and the properties foretold of missing members of the series. But what is to be done in the event of several claimants demanding to be admitted to the same place? This is a problem which chemists have to face. A very rare metal, yttrium, has been resolved by successive "fractionations" into seven metals (one of which, scandium, was wanted to fill a vacant place in Mendeléef's table) which differ but very slightly one from another. By fractionation, to take a simple example, is meant such a process as forming a nitrate of the metal, and then heating this salt to a certain temperature which is not sufficiently high to allow of the conversion of the whole of the nitrate into oxide. Some is decomposed while the rest remains as nitrate, which, being a soluble salt, can be dissolved in water. This dissolved nitrate is crystallized and heated somewhat more strongly, and the process repeated over and over again. And of the seven new metals, the real yttrium, as judged by the spectroscope, shows indications of being a mixture of five metals which cannot be distinguished by chemical methods. It might be inferred that this apparent multiplicity of metals could be explained as due to the failure on the part of the chemist to remove impurities; but Sir William Crookes is not content with this explanation. He

believes that the chemical atom of the element yttrium is not fixed ; that the number of protyle atoms which form its cluster varies, and that the five " meta-elements " are, as it were, either trying to fix into an element, or that, like a very rare species of animal (the mud-fish, for example), which is dying out because it is not fitted for its environment, it is exhibiting great variability in its expiring efforts to hold its own against its better equipped competitors. These far-reaching speculations of Sir William Crookes bring the analogies of living phenomena into the inanimate world. He speaks of the origin, predominance and decay of the elements in the same terms in which a naturalist describes the struggle for existence.

Each year our conceptions with regard to the structural constitution of matter—its architecture—become more definite. With the mind's eye we not only see it composed of separate molecules, but we can tell approximately how the atoms are placed in the molecule. We can figure to ourselves the shape of the atom-groups.

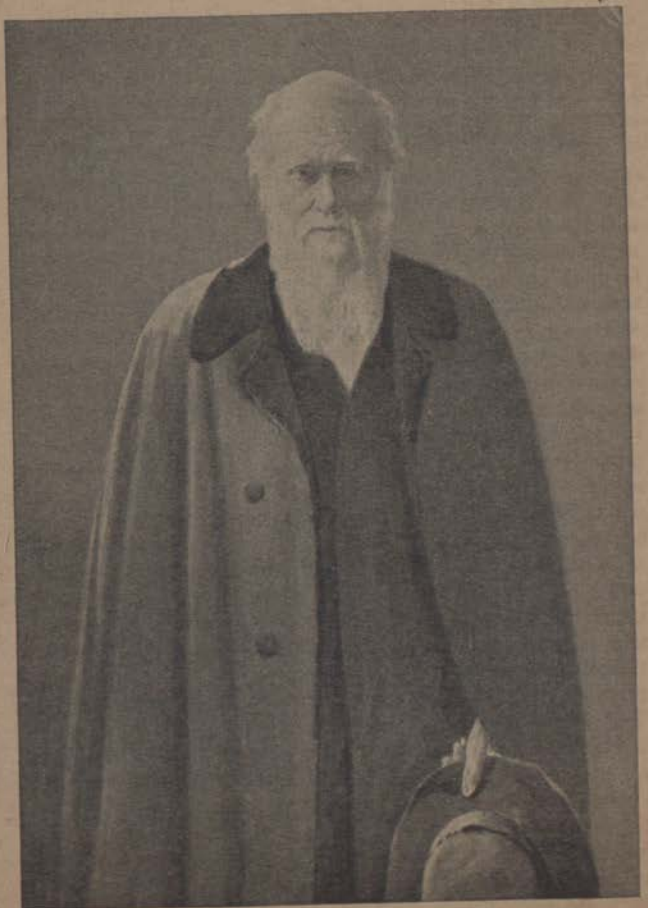
For a long time chemists have denoted compounds by graphic formulæ. They have replaced the name of a substance by an ideo-graph, which shows the number of atoms of each element in its molecule. Thus ammonia is NH_3 ; and aniline is written $N\ (C_6\ H_5)\ H_2$ to show that one of the three H.'s in ammonia is replaced by the radicle, benzene. Various diagrams are made to indicate that some elements can unite with one combining unit of hydrogen, while others will take two, three, or four. The atoms are represented as having one or more affinities, to which other atoms or radicles can be attached. The atom of carbon is tetravalent, and since each of its four affinities may be satisfied with a different element or group of elements, its compounds are exceedingly complex. The molecules of all so-called " organic " bodies are clusters of carbon-atoms united with hydrogen, oxygen or nitrogen, or with all three of these elements, and in rare cases with a metal in addition. Now, it is clear that a molecule must occupy three dimensions in space ; and if the chemist

wishes to picture its form he must use, not a flat diagram, but a solid model. He must take a stereoscopic view of the molecule. Hence the science of the architecture of matter, of the position of atoms in space, is termed stereochemistry.

That stereochemistry is more than an arbitrary system of symbols; that it is really possible to ascertain the relative positions of the atoms which compose a molecule, and therefore to form a conception of its shape, was first indicated by an observation made by Pasteur fifty years ago. It was known at that time that certain compounds when in solution rotate the plane of polarized light. The undulations which constitute a ray of light are in all planes; but if the ray is passed through a plate of the semi-transparent mineral tourmaline, cut parallel to its axis, only those vibrations which are in planes coinciding more or less with the axis of the crystal, pass through it—to vibrations in other planes tourmaline is opaque—and, in passing through, they are turned until they are all quite parallel. The mineral acts as an optical sieve. If now these polarized rays are passed through certain substances in solution, or in the crystalline form, they are twisted to the right or to the left. Pasteur discovered that there are two kinds of tartaric acid, distinguished when in solution by the fact that the one rotates a ray of polarized light to the right and the other rotates it to the left; and he found that these two forms of the acid (which appear to be absolutely identical in chemical properties as well as in specific gravity and other physical properties) differ when crystallized to this extent—the lævo-rotary crystals look like the dextro-rotary when they are seen in a looking-glass. They are reversed or enantiomorphic in the language of crystallography. This, of course, implies that they are asymmetrical.

There are two forms of ethylidene lactic acid, to take another example, the one dextro-rotary and the other lævo-rotary. In this substance the tetravalent atom, Carbon, has its four affinities satisfied with H, OH, CH_3, and COOH respectively. To gain an idea of the way in which these radicles are attached to the carbon-atom—of what is meant

by stereochemistry—the reader may cut out a tetrahedron in wood. If he then sticks pins with little heads (H = 1) and with big heads (C = 12 and O = 16) into the corners of the four-sided block to represent the four radicles with which the carbon is united, the lob-sided model which he makes may stand for one of the two varieties of lactic acid, say the dextro-rotary. If the dextro-rotary model be held before a mirror, a model of the lævo-rotary acid is seen. Of course we know nothing as to the real form of any molecule, but we may claim to have something better than a vague idea of what the molecules of different substances are relatively like. The science of stereochemistry is the product of a vast amount of chemical, mathematical, and physical research. Already very complicated molecular figures have been worked out, and the subject promises most important generalizations in the future.



CHARLES DARWIN.

1809-1882.

CHAPTER III

Origin of Species

Two hundred thousand species of insects are known, and it is estimated that four hundred and fifty thousand animals in all have been described and named. The Kew catalogue of flowering plants records one hundred and twenty thousand species, and probably the plants which do not flower are equally numerous. The total number of animals and plants already recognised as distinct and separate forms is about three-quarters of a million, and none can say how many yet remain to be described. To classify all these various forms of living things according to some intelligible scheme, is the business of the student of animated nature; at first, in ignorance of any cause for their diversity of form, botanists and zoologists thought only of so arranging them that they might know where to look for them in their museums, and how to find the name of any particular species which was not familiar, or to make sure that it had not hitherto been described and named. Thus we find Linnæus arranging plants into "orders," according to the number of their stamens—as we might classify our friends according to the number of letters in their names. Truly such a classification would be useful. We should get all the Smiths into one group and all the Robinsons into another, and when we saw a man with the Macgillicuddy features coming down the road, we should at once think of him as belonging to one of the many-lettered groups, and should know approximately in which album to look for photographs of his near relations. But we should find the five-lettered and six-lettered groups extremely cumbrous, as Linnæus found his orders Pentandria and Hexandria.

De Candolle made an immense advance when, in 1809 he

pointed out that plants have certain natural affinities and that therefore they should be classed according to the sum of these affinities. It is only in this way that a "natural classification" can be drawn up; but De Candolle bequeathed to his successors an almost endless task. How is the sum of natural affinities to be measured? How is the product of so many variants to be estimated? Root, stem, branching, thorns, leaves, stipules, bracts, inflorescence, calyx, corolla, stamens, carpels, placentation, fruits, vernation, æstivation; it is impossible to give a numerical value to each of these variable organs or characters. Who is to decide whether, and to what extent, marked similarity in one character shall outweigh dissimilarity in many others. Imagine two examiners differing as to whether A or B shall have a prize. (We are about to spoil a well-known story.) "I have given B more marks than A," says one, "and if we add your marks to mine B still comes out first, and yet you persist that A is the cleverer boy. On what do you base your conviction?" "On my general impression." "Mr ——, if your examiners had trusted to their general impression, you would never have been in a position to examine for this prize." A general impression has no value in an examination unless it be the sum of a number of particular impressions each accurately expressed in marks. There is no conceivable plan by which the value of variable characters can be marked for purposes of classification.

With the publication of the "Origin of Species" (1859) the problems of classification acquired an entirely new and, for the first time, a really natural aspect. So much clearer and more comprehensive was Charles Darwin's theorem of Natural Selection than any of the statements of Erasmus Darwin, Lamarck, St Hilaire and others who had recognised that the fact of the variability of species indicates a "progressive transmutation," that for all practical purposes it is the starting-point of the "new biology." And, although Wallace shares equally with Darwin the credit of formulating the law, the main burden of its proof was undertaken by Darwin. There

can be little doubt but that a century hence, when minor details have been forgotten, the progress marked by the enunciation of the theory of Natural Selection will be regarded as the greatest event in the history of Science, the most remarkable step forward ever taken.

It is difficult to exaggerate the magnitude of the change which the theory of Natural Selection brought into the naturalist's attitude of mind towards the subjects of his study. It gave them life. The wax-work figures which peopled his world began to move. Instead of each individual form standing still, finished, immutable, it is seen to be coming out of a past and progressing towards a future. It is no longer a perfected thing doing, as its ancestors have done, the work for which it was designed; but it is struggling towards perfection amidst a multitude of competitors. As its progress becomes faster, its species spreads over the earth; if it fall behind its neighbours in capacity for adaptation, it will shrink into an insignificant remnant. The stronger plants are ousting the weaker from soil and sunshine. Defenceless plants and animals are growing cleverer in eluding their enemies. Predatory animals are becoming more cunning in discovering the wiles of their prey, stronger in jaw and claw and clasp of limb to pierce their armour. The existence of every living thing depends upon its being able to obtain its food and to resist its enemies. The slightest balance in its favour means perpetuation, the least deficiency leads to extinction. Is the shell of a mollusc strong enough to resist the crushing grip of a lobster's claw? Will a lobster's carapace withstand the horny jaw of an octopus when its eight arms envelop it in their paralyzing embrace? Can the octopus or cuttle-fish hide its soft body from the dog-fish in search of food by suddenly changing colour from white to sea-weed brown, or by projecting into the water a cloud of ink? Our forefathers, watching this inevitable tyranny of strength and cunning felt that it was cruel. As it had been in the past it must continue to be. The weak would remain weak; the strong would continue strong. We lose

the idea of cruelty in the interest of the competition. It is a race for perfection, and the things which fail to adapt themselves must become as the graptolites, trilobites and ammonites which have long since disappeared from the earth.

Further, what is true of living things looked at as a whole is true of every organ of which they are composed. Fifty years ago it was the custom for the teacher of human anatomy, after saying all that could be said about the form and structure of the organs which were the subjects of the lesson for the day, to dwell upon their perfection as instruments designed for a particular work. He may have had his doubts, but it would have been irreverent to express them. Now, when he touches upon the mechanics of a bone, say the scapula, or of a muscle such as the plantaris, he is free to say of the former, "this bone is entirely wrong in principle, but as an adaptation of the scapula of a quadruped, which is used to transfer the weight of the trunk to the fore limb, it serves its purpose, namely, to swing the fore limb on the trunk." Or, of the latter, "This is a muscle which was of use in lower animals. It is practically useless in Man, and will in course of time be discarded. Its poor development and irregular origin and insertion shows that it is on the point of disappearing." There is not an organ in the body which is perfect, in the sense of having attained to finality, and there are many which are evidently on the downward grade. Take as an example the thymus gland, an organ which lies behind the upper part of the breast-bone. At the time of birth this organ weighs about half an ounce. During the first two years of life it grows as fast as other organs; after five it rapidly disappears. It consists of a lobulated mass of lymphoid tissue—tissue, that is to say, in which young white blood-corpuscles, or leucocytes, are being formed. Little spherical nests of epithelial cells are embedded in this tissue, as well as a number of amorphous globules termed "fuchsin-bodies," because they stain darkly with this dye. Now fuchsin-bodies are found in the olfactory apparatus of the brain, after it has begun to atrophy, and there can be no

doubt that they indicate cells, or blood, which have undergone chemical change. The nests of epithelial cells are probably the remains of gland tissue—blocked-up ducts, we may say, almost with certainty, after studying the development of the body. Here then is an organ which grows like a gland (or like an organ of respiration), although it is not found as a functional gland in any vertebrate. What does it mean in Man? It is a manuscript which cannot be read. The characters in which it is written were obsolete before the earliest fish came into existence. Why then has it been retained? For the sake of the palimpsest which we can read. Like all other glands formed in connection with the front part of the alimentary canal it is surrounded by lymphoid tissue. For the sake of this crossed writing it is retained in every individual until he reaches an age at which his great need of a nursery for young leucocytes has lessened. After that it disappears.

It is not only in living things as they appear in the adult condition that the biologist traces adaptation, now that the law of evolution has been formulated, but in every stage of growth. As he watches the changes through which the single-celled ovum evolves into the fully grown animal, he sees the race of which this particular species is the heir passing through all the stages which have marked its history from age to age. In a few days, or weeks, or months a drama is acted which has taken geological æons to rehearse, for every individual recapitulates in its growth the successive stages to which its ancestors attained, and at which they severally stopped. What explanation could the teacher of fifty years ago give of the gill-slits or tail or a hundred other resemblances to lower vertebrates which the human embryo presents in the course of its development? They are by no means necessary preparations for adult structure. They never can be useful. Not infrequently they are mischievous. Man's organs reach their permanent form by many a roundabout road. These digressions are indications of the tenacity of Nature's memory. She can attain her goal only by tracing over again—with a jump here and a

short cut there it may be, but without letting go of the clue—the path which she followed when she first discovered it.

We are now in a position to understand the influence which Darwin's theorem has had upon the taxonomist. It is no longer enough that he should classify living things according to their natural affinities—he must group them according to their proximity to one another on the ancestral tree. His classes are the several stems of this tree, his orders its main branches. Its small branches are genera and its twigs species. Their "natural affinities" do, of course, indicate relationship, but the taxonomist must beware of mere resemblances. He can only be sure that he has traced their pedigree when he finds two extant forms uniting—losing their differences—in a fossil ancestor. The geological record is, however, so imperfect that it is but seldom that certainty can be claimed.

In any attempt at classifying animals a great and hitherto impassable gap is found between invertebrates and vertebrates. There is, as it were, a wedge-shaped blank in the picture of the ancestral tree. Evidently a vast number of intermediate forms have died out, leaving, according to the common reading of the rock-record, no trace behind. When the highest of the invertebrates of the epoch at which the change occurred began to assume what is now known as the vertebrate type its transitional form cannot have favoured it much in the struggle for existence. Of its successors but few survived, and these only such species as inclined strongly towards the vertebrate type. The new type was therefore established with comparative rapidity. But, when once it had acquired something like permanent character, this form of animal showed that it could not only hold its own against invertebrates, but that it contained a potentiality for development into "a great nation." It is difficult to imagine the conditions which favoured this remarkable transition. Probably it is better not to try. The facts remain that whereas it can be proved from embryological evidence that the vertebrate had an invertebrate ancestor, and whereas the differ-

ence between the two types is of the most pronounced kind, zoologists are not agreed that any indubitably intermediate forms have been found, either extant or extinct.

Anyone who has taken the facts above stated into consideration will anticipate a bold theory of the transition from an invertebrate to a vertebrate type, but the more he dwells upon the essential differences between the two the more clearly will he see that only a bold theory can hope to justify itself. The most striking differences are these: The vertebrate has a backbone which gives off two series of bony arches, the one dorsal (the vertebral arches) to enclose the spinal cord, the other ventral—jaws, hyoid arch and ribs—to enclose the alimentary canal and viscera. When an invertebrate has a skeleton it is usually external, like the calcareous case of a lobster, for example. The vertebrate central nervous system (brain and spinal cord) lies entirely on the dorsal side of the vertebral column and therefore on the dorsal side of the alimentary canal. The central nervous system of an invertebrate is partly dorsal, partly ventral. In the octopus, for example, which (with the exception of spiders and scorpions, perhaps) has the nearest approach to a brain found in any invertebrate, the nervous ganglia are collected into a group, enclosed by a rudimentary cartilaginous skull, which is pierced by the gullet. The gullet goes straight through the middle of the skull and brain.

We have said that the vertebrate passes through invertebrate stages during its early growth, or in other words, that both vertebrate and invertebrate pass through the same stages up to a certain date. They may in a few words be described as follows: First, the one-celled ovum divides into a "mulberry mass." This mass next becomes a hollow sphere. One side of the ball is then pitted in, so that a cup (the gastrula) is made, lined by a sheet of cells, the endoderm, covered by a sheet of cells, the ectoderm. But little change is needed to make such an embryo into a sea-anemone. The endoderm is its stomach; the ectoderm, its body-wall; the space between them, its body cavity. With a fringe of

tentacles round the mouth it is practically complete. Now, however great may be the elaboration of this type in invertebrates its main features remain the same; the hole left by the pitting-in is the mouth; the nervous system is formed as a circle round this hole. The first difficulty, in continuing the line from the invertebrate to the vertebrate sub-kingdom, is met with when we try to recognize these early stages in the latter. The vertebrate also shows a pitting-in, the "primitive streak" and blastopore, followed by an up-growth of the "medullary folds," the walls of which grow into the brain and spinal cord. If this, as a whole, corresponds to the pitting-in to form the stomach of the gastrula it follows that in vertebrates a new stomach has been acquired; while the old stomach has become the ventricles of the brain and the central canal of the spinal cord. How has the new alimentary canal been formed? Vertebrate embryos (and many invertebrate embryos also) are provided with a store of food —the yolk. For the purpose of tapping this supply of food a diverticulum grows out from the hinder end of the neurenteric canal. This, according to the view about to be enunciated, becomes in vertebrates the permanent alimentary canal. But it has no opening to the exterior; and the phenomenon which all zoologists have had to try to explain is the formation of a new mouth which occurs at the anterior end of the vertebrate embryo, perforating through into the so-called fore-gut.

Taking the widest view of these and of many other differences in structure which distinguish the vertebrate from the invertebrate, Dr Gaskell has offered us a startling explanation of the transformation which has occurred. All those parts of the invertebrate body which are median and unpaired—all that makes up the body of the sea-anemone that is to say, but not the limbs of insects, lobsters, and other bilaterally symmetrical animals — lie on the dorsal side of the vertebral column. The invertebrate alimentary canal is our neural canal. Its stomach is the ventricular cavity in our brain—its gullet passed through a hole, still to be traced, in the base of our skull. Every anatomist re-

cognises that the central nervous system is the most conservative system in the body. It is the first to be formed in the embryo, the last to adapt itself to changes in other organs. Nerves may change their course, but their centres in the cerebro-spinal axis remain unaltered. The whole animal may alter in appearance, but the nervous system is not essentially affected. It is the central system about which the rest of the body grows; and there can be little doubt but that the central nervous organs in man are homologous with those of arthropods or molluscs, little as any other portions of our body find their counterpart in these animals. In the invertebrate the central nervous system consists of a collar round the œsophagus, certain ganglia in the head, and a double chain of ganglia along the ventral side of the alimentary canal. These ganglia, says Dr Gaskell, which have already coalesced in the highest invertebrates, become the brain and spinal cord. Increasing vastly in importance as the animal series is ascended, they have grown round, and blocked in, its primitive alimentary canal.

If we wish to trace the history of the greater part of our body, we must understand that there has been much shifting of functions among the organs. The stomach, the liver, and, in a certain sense, the lungs are new. Indeed our thyroid body—the two lobes at the side of the larynx, which sometimes hypertrophy into goitre—an organ of which hitherto neither anatomists nor physiologists have been able to give an explanation, is a disused reproductive organ of our invertebrate ancestors. Our two eyes may be represented in the ocelli and lateral eyes of some invertebrates, but they are not their median eyes. The eye of an octopus looks very much like that of a fish, but it has long been known that it is constructed on quite a different plan. In the eye of the octopus the rods and cones, the elongated cells which are sensitive to light, are directed forwards; in the fish they are directed backwards, and the front of the retina consists of a sheet of transparent nerve fibres. The eye of the vertebrate is, therefore, the in-

vertebrate eye turned inside out. Ingenious hypotheses have been formulated to explain how this puzzling involution came about. There is no need of any hypothesis according to Dr Gaskell. Deeply seated in the centre of our brain is a little conical organ, the pineal body, which has acquired a spurious fame, because Descartes, looking at it in its relation to the great hemispheres of the brain and the cerebellum which overarch it, and thinking how closely it resembled an organist seated at an organ, imagined that it might be the seat of the soul. The pineal body in certain curiously archaic reptiles, particularly Hatteria punctata of New Zealand, has a long stalk and reaches to a hole in the roof of the skull, which is closed by semitransparent membrane. Its structure shows most clearly that it is an eye formed on the invertebrate plan. Hatteria has two inverted eyes, as we may call them, as well as its cyclopean pineal eye in the middle of its head; but Dr Gaskell has shown from its development in the larva of the lamprey, that the pineal eye was formerly paired, and that its connections with the brain are similar to those of the median eyes of invertebrate animals. Lastly, to touch upon the question of the new mouth of vertebrates: the anterior part of the new gut was originally a respiratory chamber, which afterwards served as an alimentary canal. This respiratory chamber was formed, as it is now formed in the scorpion-group, by the insinking of respiratory apparatus, which in other arthropods, such as lobsters, stand out on the underside of the head. Indeed the nearest approach which we can make to picturing our ancestor in the direct line, at the point at which the vertebrate and the invertebrate sub-kingdoms branched off, is to represent him as resembling one of the old extinct sea-scorpions; and the earliest animal for which we can find a place in our pedigree after the separation took place is the earliest known fish, thycotis, which is found in Upper Silurian strata. This fish belongs to a long extinct group, the cephalaspids, which present many points of resemblance with the lamprey in its larval stage, the lowest of existing fishes; while, on the

other hand, they show many indications of kinship with the trilobites and old sea-scorpions.

Dr Gaskell's views, which he has advocated with great force and ingenuity, have been much discussed at recent meetings of the British Association and other scientific societies. The majority of zoologists are opposed to them; but, even if it were otherwise, it would be going beyond our province to express an opinion upon any hypothesis which is still under discussion. We wish to introduce the reader to the problems which are occupying the attention of scientific men without prejudicing his judgement; and certainly no more striking illustration could be cited of the profound change which Darwin's doctrine has effected in biological thought. This missing chapter in the history of the animal kingdom has to be written, but no one, thirty years ago, would have ventured on so bold a rendering.

The biologist first observes and collects. He then classifies, empirically to begin with, but according to principle later on. When he surveys the immense variety of animals and plants, the question naturally presents itself to his mind. Why so many? How did this vast array come into existence?

Certain facts are quite clear. The conditions which have obtained on the globe since first it was habitable by living things have undergone great and progressive changes. They have also fluctuated from time to time. Plants and animals which could live upon the earth or upon a particular part of the earth in one geological epoch would have been killed off in the next. Fossil-forms make their appearance and disappear in successive strata. As stratum follows upon stratum the number and variety of fossils increases, and the specialization of their structure also increases progressively from period to period.

No one who knows these facts can fail to draw the conclusion that transmutation of species in the direction of improvement or evolution has occurred. The question which biologists are debating at the present time is, What is the cause of evolution?

Lamarck recognised that the conditions of life, the environment, cause changes in the individual. He supposed that these changes being transmitted to the offspring lead to progressive transmutation.

Darwin laid stress upon the fact that in the struggle for existence Nature encourages only the more fit. As all but the more fit die out without reproducing their kind, the fitness of the species which survive continually increases.

The great question now at issue is: What is the cause of the initial variation which gives to Nature a diversity of material, less fit, equally fit, and more fit, from which to select?

The only explanation of variation is based upon the "Lamarckian factors," or the proposition that the increased growth which use induces is transmitted by a parent to its offspring. Improvement is, from this point of view, the direct effect of environment, since acquired characters are inherited.

But Wallace, Weissmann, and most post-Darwinians decline to accept this theorem. Some take the *a priori* ground that the transmission of acquired characters is incomprehensible. Reproduction means, as they point out, that the parent divides into two parts, one so large as to be practically unaffected by the division; the other a minute cell, the ovule in a carpel, the pollen grain in an anther or the corresponding cells in the two sexes of animals. Is it conceivable, they ask, that the whole of the male parent, with his acquired peculiarities, is mirrored in his "gamete," and the whole of the female in hers? Other biologists decline to accept the doctrine of the transmission of acquired characters, on the ground that such transmission has never been proved under any conditions we are able to arrange, or within any period of time over which observations extend. We have, for example, instances of the mutilation of thousands of successive generations without any tendency towards the diminution of the organ removed. Every cur's puppy flourishes a tail—does its best to rise to the dignity of a dog—centuries after the passing of a law that all, except the dogs of the

nobility who enjoyed sporting rights, should be curtailed (*court taillé*). But for reasons into which we cannot enter the evidence from mutilation is by some biologists (by Darwin himself) ruled out of court.

The adaptation of the individual to his environment is a matter of common observation. A blacksmith's biceps are bigger than those of a clerk. A seed sown in a new soil and under a new climate produces a plant different in many respects from its parent. But are these peculiarities transmitted to offspring? If it could be shown that the seeds of the transported plant, when sown in the original habitat of the species, produce plants which are unlike their wild neighbours (in respects which cannot be accounted for by supposing that the seeds have stored more food-materials, or less, than they would have stored in their original habitat), the inheritance of acquired characters would be proved. Unfortunately, if we give the plants a few generations in which to render their new features pronounced, we give time for "natural selection" to obscure the result.

The alternative to the doctrine of the inheritance of acquired characters is not an explanation but a statement, although it may be qualified by various mediate theories of "germ-plasm," "heredity," etc. It is pointed out, as a matter of common observation, that when two "gametes" have fused into a "zygote," this fertilized cell grows into an individual which reproduces neither of its parents with exactness, nor is it, so to speak, the mean of the two. Variation is therefore a fact whatever may be its cause, and since but a small fraction of all the zygotes produced develop into plants or animals which live to reproduce in their turn, nature has a chance of eliminating all but favourable variations. Of the variability of the zygotes we know nothing. We only know that the individuals into which they develop vary. We cannot say whether, if the conditions as to supply of food and incidence of external forces were identical, the individuals would be identical, because such absolute identity of conditions is unattainable. We only know that the zygotes

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contain a potentiality of variability, which after all comes to the same thing.

The "New Darwinism" has given rise to an extensive literature, and many proximate theories, or rather formularies, have been enunciated, but the main problem is still unsolved. The doctrine of Natural Selection declares that favourable variations are perpetuated. The explanation which is usually styled "Lamarckian," gives as the cause of variation the tendency of the offspring to inherit, in a more or less pronounced degree, the characters acquired by its parents. Weissmannism makes a tendency to vary an essential quality of germ-plasm, but gives no explanation of its cause.

When the question is looked at in its broadest aspects it is evident that since the world became habitable the conditions of existence have undergone incessant change. Living things have changed. Collectively, they have continuously adapted themselves to their environment. Therefore, whatever may be the proximate cause of their variability it is ultimately due to the action of the environment.

CHAPTER IV

The Cause of the Coagulation of the Blood: a Problem in Physiology

If the state of development of a science may be judged by the amount of literature to which it has given rise, without regarding its accuracy either in fact or inference, Physiology attained to considerable proportions even among the Egyptians; which would place it among the oldest of the sciences. If, on the contrary, the development of a science varies as the truth of its data and the finality of its theories, Physiology is modern indeed, and has much progress still to make. It is not to be wondered at that the working of the animal body has at all times occupied the thoughts of philosophers.

Physiology differs from most other branches of science in that it has no predominant problems. For ages its votaries were engaged in a vague quest for the Principle of Life, but as knowledge increased it was realised that the phenomena exhibited by a living thing are, in every respect, comparable to, are indeed the results of, the action of forces in the world outside the body. The doctrine of Vitalism has been abandoned. No longer does the physiologist seek for any wide generalization which shall illuminate every department of his subject. He recognises that as the body consists of many organs, each organ of tissues, and every tissue of cells, he has before him a vast number of problems all of equal importance to the complete understanding of the mechanism of the living body.

We may select as illustrations of the methods of the science two problems of different orders: (1) the cause of the coagulation of the blood; (2) the nature of the control which the nervous system exerts over the body.

Contributions towards the solution of these problems have been made by the naturalists of all ages, although it still remains for the scientific workers of the future to discover facts which must be added to the chain of evidence before the final verdict is given. The history of these problems illustrates in a striking way the natural growth of Science.

That blood clots a few minutes after it is shed is an observation which could not fail to attract the attention of primitive man. The more primitive the man, the more numerous were the opportunities which he enjoyed of observing this phenomenon.

Why does blood clot when out of the body, and why does it not clot while it remains within the blood-vessels?

Aristotle knew the immediate cause of coagulation; that it is due to the formation of fibrin (or fibres as he called them), and his explanation of why the fibres form was a natural one, although the very reverse of the true explanation, as we shall see. "Coagulation occurs in the earthy part of the blood, that is in the fibres, during the evaporation of the moisture." "If the fibres are removed from the blood of a bull"—if it is whipped with a bundle of twigs so that the fibres are collected on the twigs—"the blood will not clot." "If the fibres be left the fluid coagulates, as does also mud, under the influence of cold. For when the heat is expelled by the cold, the fluid, as has been already stated, passes off with it by evaporation, and the residue is dried up and solidified, not by heat but by cold. So long, however, as the blood is in the body it is kept fluid by animal heat." [1] To the idea of the escape of heat which was set forth in great detail by Aristotle because he believed that the process of coagulation resembled the setting of a solution of gelatin, was subsequently added the explanation that the blood is kept from coagulating as long as it is in a state of motion, but clots when it comes to rest. What explanation could be more natural? The soldier was found on the battlefield

[1] "On the Parts of Animals," book ii., chap. iv Dr Ogle's translation.

lying in a pool of blood which had come to rest, grown cold, and coagulated. The clotting was due to cold and rest.

This was the accepted explanation until the middle of the last century. Indeed it held its own until much later notwithstanding Hewson's demonstration of its insufficiency. In medical writings of the eighteenth century we constantly meet with the statements that "Blood coagulates when exposed to a moderate degree of cold." "Blood coagulates when it is deprived of the attrition to which it is exposed when circulating within the vessels of the body." Such negative statements are unexceptionable. But we also meet with positive assertions which certainly were not based upon experience. "The blood will not coagulate if the cup into which it is received be kept at the temperature of the body." "If the blood be kept in motion by rapid stirring with a glass rod it is hindered from setting a clot." It would seem to us, with our modern axiom "Check your references" to have been easy to put such assertions to the test, especially easy in the days when the traditions of his profession directed a surgeon to let blood in almost every case he attended, as an obviously remedial measure which he might safely adopt before he proceeded to inquire as to what was amiss with the patient. But these statements were not based upon observation. They illustrate a very different method which was more commonly pursued by the medical writers of that time. Accepting the authority of Aristotle and his successors as unquestionable, they argued that if blood coagulates when it leaves the body, because it grows cold and comes to rest, it follows that it will not coagulate if it is kept warm and in motion. This conclusion being unassailable, they stated the phenomena, which they knew must hold good, as facts.

William Hewson, "F.R.S. and Teacher of Anatomy," commenced, in 1767, a series of experiments which he published under the title of *An Inquiry into the Properties of the Blood.* His methods are admirable and his conclusions are drawn with the modesty which should always charac-

terize scientific thought. "Two of the latest writers on this subject agree that if fresh blood be received into a cup, and that cup put into water heated to 98°, it will not separate; nay, they even say that it will not coagulate; but this, I am persuaded from experiments, is ill-founded."[1] After reciting experiments which showed that blood kept at the body temperature, as nearly as his apparatus allowed, coagulated even sooner than the same blood left exposed to the temperature of the air, he proceeds to put the matter to a crucial test. He ligatures a vein in the neck of a dog in two places and then covers it with the skin to prevent its cooling. Opening the vein after an interval he found the blood in it coagulated, although coagulation was very considerably delayed. In this experiment the blood was kept warm, but it was allowed to come to rest. "Blood, when received into a basin very soon jellies or coagulates. The circumstances in which it now differs from what it was in the veins are these: it is exposed to the air, to cold, and is at rest. The question is, to which of these circumstances its coagulation whilst in the basin is chiefly owing. As the subject seemed to me of importance, I have endeavoured to ascertain the circumstance to which this coagulation is owing by several experiments, in each of which the blood was generally exposed to but one of the suspected causes at a time." He repeats the experiment of ligaturing the vein in two places. "From several experiments made in this way, I found in general that after being at rest for ten minutes, the blood continued fluid; nay, that after being at rest for three hours and a quarter, above two-thirds of it were still fluid, though it coagulated afterwards. Now the blood when taken from a vein of the same animal was completely jellied in about seven minutes. The coagulation of the blood in the basin and of that which is at rest are so different, that rest alone cannot be supposed to be the cause of the coagulation out of the body." This is not clearly expressed, but it

1 "An Experimental Inquiry into the Properties of the Blood," 2nd edition, p. 3, 1772.

evidently means that were rest the sole cause of coagulation the blood at rest in the vein would have coagulated as quickly as the blood in the basin. We cannot follow Hewson further in his investigations. He cuts out the ligatured vein and freezes it and shows that after it has been thawed the blood is still fluid and still ready to coagulate. He places the excised vein in water which he warms to various temperatures, and finds that it is not immediately coagulated at 114° F., although it is at 120° F. And lest this result should be regarded as a heat-coagulation, such as occurs when a solution of white of egg is heated, and not the natural process, "It may be necessary to observe here, that the part coagulated was only the lymph (plasma); for the *serum* requires a much greater heat to fix it, that is a heat of 160°, as will appear hereafter." Hewson's methods closely resemble those of his contemporaries William and John Hunter, Henry Cavendish, Antoine Laurent Lavoisier. We have given these few extracts from Hewson's book in his own words because they show how thoroughly he was embued with the great principle which may be said to have dawned upon Science at this period, supplying a code of rules to the observance of which all subsequent advance was due—the principle of the control-experiment. He arranged that only one of the suspected causes should act at a time, and he had the scientific insight which warned him that one experiment under natural conditions is better than a hundred in which all the conditions are artificial. Had Hewson examined the blood only after it was drawn from the body, he would have placed it in contact with a china or metal cup, would have exposed it to air and to dust, would have allowed its halitus or volatile spirit to escape, and in many other respects he would have introduced conditions any one of which he might have mistaken, as all in turn were mistaken by his successors, as the *vera causa* of coagulation.

Whence does the fibrin come? What is its condition in circulating blood? Prevost and Dumas (1823) studied the chemical properties of fibrin, and decided correctly that it

cannot be in a condition of solution in circulating blood. It is not a soluble substance. They also observed under the microscope that multitudes of globules, resembling the nuclei of blood-corpuscles, were entangled in the clot, and they inferred that the fibrin was present in the blood as fibrin, but was in some way fixed to, or formed part of, the corpuscles. Their description is not sufficiently clear to enable one to say exactly what was their idea of the relation of the fibrin to the corpuscles. "The attraction which keeps the red matter fixed around the white globules having ceased along with the motion of the fluid, these globules are left at liberty to obey the force which tends to make them combine and form a network, in the meshes or around the plates of which the colouring matter is included along with a great quantity of particles which have escaped this spontaneous decomposition."[1] Milne-Edwards tells us that "this theory has been adopted by the greater number of the physiologists of the present day."[2] For his own part, however, he considered that the fibrin "is merely suspended in the mass of the blood in a state of extreme subdivision, and possessed of transparency too perfect to admit of its being seen amidst the surrounding fluid."

That fibrin is not present in the blood before coagulation had already been proved by Johannes Müller (1831), but the importance of his observations was not recognised until some years later. Müller placed frog's blood (in which the corpuscles are four times as large as in human blood) upon a filter-paper—after diluting it with thin syrup to delay coagulation. He found that the fluid (plasma) which passed through the filter-paper, completely unmixed with corpuscles, clotted just as the whole blood would have done. Clearly, therefore, a soluble antecedent of fibrin is present in circulating blood. What is the antecedent, or what are the antecedents, of fibrin?

The key to this problem was provided by an extremely

1 *Annales de Chimie*, vol. 23, p. 51.

2 "*Cyclopædia of Anatomy and Physiology*," vol. i., p. 43, 1835-6.

ready observer, Andrew Buchanan (1830), who noticed that accumulations of inflammatory lymph, which the surgeon is called upon to "tap," sometimes coagulate after removal from the body and at other times do not. Searching for the cause of the clotting, he observed further, that if during the operation a little blood obtains access to it, the lymph clots. He therefore added to the lymph the several constituents of the blood in order that he might ascertain the real exciting cause. He found that the red corpuscles were not necessary, since serum or even the washings from a blood-clot would answer equally well. Indeed it was not necessary to use any of the constituents of blood. He found that two exuded fluids, such as the lymph which accumulates in the chest in pleurisy and that which accumulates in the abdomen in dropsy, neither of which has any tendency to clot when left to itself, sometimes clot when mixed together. Coagulation must therefore be due to the interaction of two substances.

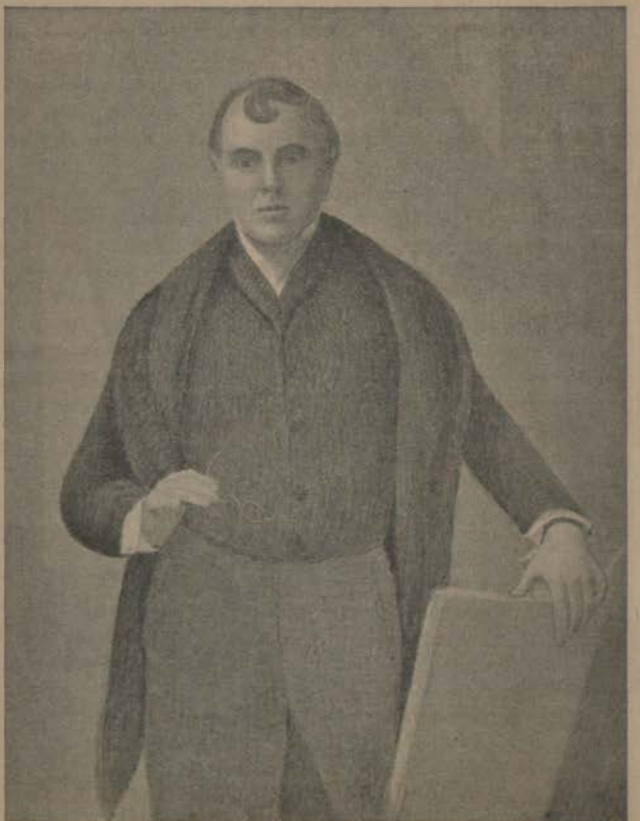
The problem now entered a chemical phase. Denis (1859), when investigating the proteid (albuminoid) constituents of blood, found that if he saturated plasma (blood from which the corpuscles have been removed before clotting) with sodic sulphate, a sticky mass was precipitated which, when re-dissolved in pure water, gives a clot. This brings the clotting-property home to the "globulins" in the blood, since albumin is not precipitated by sodic sulphate.

1861.—Schmidt, remembering Buchanan's observations, resolved to obtain Denis' "plasmine" as two separate globulins. He therefore repeated the experiment upon each of the exuded lymphs, which clotted when mixed but would not clot separately. He obtained two globulins which he named "fibrinogen" and "fibrinoplastin," dissolved them separately in water, and found that neither solution coagulated; but fibrin appeared when they were mixed. Proceeding however to obtain them by another method in a purer state, he found that his two globulins, when precipitated by a stream of carbonic acid gas, would not cause a clot, either when

dissolved separately or when combined. However, some of the washings of a blood-clot added to the mixture caused it to coagulate. Schmidt therefore concluded that three things are needed, fibrinogen, fibrinoplastin, and "blood-ferment." But in drawing this conclusion he neglected the indispensable scientific precaution to which we have already called attention. He overlooked the necessity for arranging a "control-experiment." Hammersten showed that Schmidt might have left fibrinoplastin out of the mixture. When he precipitated it in a pure state he freed it from the only essential constituent, the "ferment." Fibrinogen *plus* ferment, yields a clot. Fibrinogen is dissolved in the plasma and does not become insoluble until it is acted upon by the so-called ferment. The ferment is set free on the disintegration of white blood-corpuscles (or of some other formed constituents of the blood); and the reason for the delay in coagulation which Hewson observed, when by ligaturing a vein in two places he converted it into a bag of blood, is that the corpuscles, when kept in a natural condition, retain their vitality for a long time. With many blunders and much following of false scents physiologists have gradually traced the blood-clot to a soluble globulin, fibrinogen, which is changed into fibrin by the action of a "ferment." But a complete explanation is yet to seek. There are difficulties still which need to be cleared up. In the first place it is known that if all salts of lime are removed from the blood it will not clot. Therefore lime is necessary to one or other of the factors. Either it combines with the fibrinogen at the time when it is converted into fibrin, which seems to be disproved by the fact that no more lime can be found in fibrin than in fibrinogen; or by uniting with an antecedent of the ferment it develops the activity of this substance. Secondly, the action of the nucleo-proteid which is called blood-ferment differs widely from that of the vast majority of substances which are classed as ferments. Ferments are bodies which induce changes in other bodies by mere contact, without themselves taking part in the change; and the chemical action, which they induce is usually a hydrolysis, or union with water, but

fibrin seems to contain less water than fibrinogen. Blood-ferment, like the ferment of rennet which curdles milk, produces an insoluble and not a more soluble substance. It is however possible that fibrinogen is changed by the ferment into a substance containing more water in its molecule, and that this substance divides into the insoluble fibrin and some other substance, probably a globulin, which is freely soluble. The fact that the fibrin obtained from a given quantity of fibrinogen weighs considerably less than the fibrinogen indicates that such a cleavage occurs, as it undoubtedly does in the coagulation of milk. Thirdly, if the formation of fibrin is due to a reaction between fibrinogen and fibrin-ferment in the presence of salts of lime, the injection of fibrin-ferment into the circulating blood should invariably produce coagulation, whereas it usually fails to bring about this result.

The cause of the coagulation of the blood is perhaps the oldest of physiological problems. Its history is typical of the progress of the science, and not less characteristic is its position at the present time. Like most other problems it is almost but not quite solved, and it is doubtful whether this, or any other question which the physiologist is asked, can ever be so answered as to leave nothing more to say. As knowledge increases we see farther into the unknown, and each decade is less notable for the questions which it lays to rest than for the further questions to which the process of answering gives rise.



SIR CHARLES BELL

1774-1842

CHAPTER V

The Functions of Nerve-Fibres and Nerve-Cells

On the view which we take as to the nature and amount of control which the nervous system exerts over the organs depends, to a certain extent, our conception of the causes which lead the organs to do their work. There is no other problem in physiology of so general a character as this. The simplest animals which exist at the present time are destitute of any tissue specially set apart for the control of the other tissues, and it may be assumed that the animals which earliest appeared upon the earth were in this respect like the simplest animals now extant. The unicellular amœba which crawls about the stalks of duck-weed in our ponds exhibits in its movements what, in higher animals, we should regard as evidences of purpose. It moves in the direction of its food. Yet the appreciation of the direction in which food lies, and the guidance of its movements are due to the properties of its general body-protoplasm, and not to any specialized internal structure. The simplest multicellular animals (if some of the composite animals which may be regarded as colonies of cells rather than compound individuals are excluded) devote certain cells to the reception of information from the outer world, and other cells, prolonged into fibres, to the transmission of messages to their contractile tissue. A nerve-cell and its fibre come into existence in order that they may establish a communication between the outer world and the muscle-cells by which an animal moves. There is no *a priori* reason why the nerve-cell or the nerve-fibre should in any way select or elaborate the messages which it transmits, still less has it any antecedent or prescriptive right to decide to which of all the

contractile cells its messages shall be delivered. Shall the type-writing machine decide what letter it will write, or whether it shall print it in small type or capitals when the key marked m or n is pressed? In its original form the nervous system is as mechanical in its action as a type-writing machine. But in the complex state of organization to which it attains in the higher animals how far it seems to have advanced upon a mere arrangement of levers pressed down by forces from the outer world! And when we, by introspection, study its working in ourselves, when we feel it selecting, suppressing, exaggerating, and apparently originating the messages which it transmits, how far it seems from an automatic machine played upon by our environment! Herein lies the crux of this great problem. The animal is a mechanism. The animal has a Will. The physiologist who looks upon the nervous system as a means of communication between sense-organs and muscles, is content to study its connections. The psychologist who regards it as the tissue in which impulses impressed upon the body from the outer world are "worked-up," seeks for some protoplasmic substance, which owing to its molecular instability, and the chemical changes which consequently occur, is capable of manufacturing impulses, or at any rate of storing and profoundly modifying those which pass through it.

The controversy between those who hold the mechanical view and those who incline towards the automatic theory, as physiologists would term it—meaning thereby the conception of the nervous system as an originator of nerve-currents—is as old as the science of physiology; not that we wish to imply that the science properly so-called has as yet reached "years of discretion." It is useless to ask when it first assumed the exactitude of a science. We must grant it a nebular origin. Descartes in the seventeenth century argues that animals are, as we should term them, reflex machines, incapable of feeling pain, or rather, of knowing that they feel—it is very difficult to translate

Descartes' metaphysical theories into plain language. He considered that animals feel, but inasmuch as they do not realise the self which feels, they are conscious automata. "It is my opinion that animals do not see as we see, because we feel [know] that we see." Like somnambulists or men in a hypnotic condition, they respond, without knowing it, to external impressions. Had Descartes known more about the physiology of the nervous system he would have said that all the activities of animals are reflex phenomena, inevitable although conscious responses to stimuli. We find the physiologists of twenty or thirty years ago inclining to the opposite extreme, and constructing a nervous system out of their own consciousness, upon the most approved model of a government department; every little clump of nerve-cells an office with a certain share of authority, and well-defined responsibilities towards the officials higher in command. They imagined that they could find the outer world, as they knew it, mirrored in the inner world, which they did not know; and seeing that no great administrative department can work effectively, unless there be an extensive delegation of authority with an equally elaborate system of surveillance, they allotted duties to the various parts of the nervous system according to a similar plan. Their "automatic centres" for the control of the heart and intestines, the movements of respiration, &c., have been shown the mere reflex mechanisms which they really are. All their little dignity is denied them. They are degraded to the position of centres of reflex action, mere transmitting stations, that is to say. Looking at the matter from the widest point of view, even Man himself is a reflex machine. He is kept awake by the ceaseless impact of external forces. His running to and fro is the mechanical effect which these forces produce, when, on being passed through to his muscles, they upset the unstable molecules of those organs. The case is recorded of a man in whom disease of the nervous system had advanced until he was blind with one eye, deaf with both ears, and had lost cutaneous sensation. One eye alone of all his sense-organs was left to

give him information of the outer world. When this was closed he went to sleep. There can be little doubt, as Sir Michael Foster observes, that if the brain were cut off from all external stimuli, "volitional and other psychical processes would soon come to a standstill, and consciousness vanish." If, therefore, we look at the nervous system, as a whole, from a purely physiological standpoint—we have already touched upon the problem of consciousness—we find it a mere transmitter of impulses. How much more should we expect to find this true of each separate nerve-cell and its conducting fibre?

We will try to give a very brief historical sketch of the problem, which for clearness we will define as follows: Does the nervous system control the tissues in any sense other than that of transmitting to them, intact and unchanged, the impulses which originate in its terminations either on the surface of the body or within it? And since the only element of nervous tissue which can be imagined as manipulating messages in the course of their transmission is, as we shall presently find, the nerve-cell, the question may be reduced to this simple form —Has the nerve-cell any functions beyond that of providing for the nutrition of the fibre which grows out of it?

The first great step in nerve-physiology was taken by Sir Charles Bell, when (in 1811) he proved that of the two roots by which every spinal nerve is attached to the spinal cord, the one, the posterior, conducts sensory impulses towards the centre; the other, the anterior, conducts motor impulses towards the periphery.

Bell's discoveries suggested various investigations to Johannes Müller (1832), the results of which caused him to draw wide conclusions. He pointed out that when a man receives a blow on the eye, although the bruising of the eyelids causes pain, the only message which the optic nerve transmits is a report to the brain that stars have flashed their light upon the retina; that when the auditory nerve is irritated, the patient hears a noise; that when a nerve going to a gland is stimulated, a flow of secretion follows; or to a

muscle, contraction is induced, and so forth. The result of stimulating a nerve is to produce an effect of the same kind as that which the impulses ordinarily travelling along the nerve produce. So far Müller was right, but he generalised his results in the "law of the specific energy of nerves," in which he wrongly attributed the specific effects to the nerves and not, as we do now, to the organs of the brain to which they deliver their messages. "A sensory nerve is not merely a passive conductor, but each nerve from an organ of special sense possesses certain inalienable forces or qualities which the causes of sensations do but excite and render apparent. Sensation is therefore the transmission to consciousness, not of a quality or of a state of external bodies, but of a quality or of a state of our nerves, a state to which the external cause gives origin." "This truth, which results from a simple and impartial analysis of facts, not only leads us to recognise that the different sensory nerves are animated by special forces independent of the general difference which distinguishes them from motor nerves, but also points out the means of setting physiology free for ever from a host of errors concerning the alleged possibility of replacing one nerve by another."

With a view to testing the truth of this law of the specific energy of nerves, many attempts were made to make nerves join other trunks than their own. When a nerve has been divided, its cut ends, if they are placed in contact, join again. If it be a motor nerve, the fibres on the central (cerebro-spinal) side of the injury, which are the processes of cells in the spinal cord, grow down into the peripheral portion until they find the muscle-fibres from which they have been severed. A sensory nerve also if it be divided, grows centrifugally, because its fibres are the processes of cells which lie in the spinal ganglia, just outside the spinal cord. But the attempt to cause the central stump of a cut motor nerve *A* to grow downwards into the peripheral portion of a cut sensory nerve *B* is an experiment foredoomed to failure. Nothing would be gained by crossing two motor nerves,

since they both carry impulses of the same kind, and unfortunately the nerves of special sense do not allow of the experiment. It is not possible, for example, to cross the nerve of taste with the nerve of hearing.

Müller was mistaken in attributing the specific effects of stimulating the several sensory nerves to the nerves themselves. It was recognised by Vulpian (1866) that "all nerves—sensory, motor, vaso-motor, and others—have the same properties, and are only distinct in their effects. This question is of the highest importance for general physiology. It dominates the whole physiology of nerve-fibres." Many observations made since Vulpian wrote have shown that a nerve has no functions more *specific* than those of a telegraph wire. It conducts impulses. If a motor nerve is stimulated, in the middle of its course, by an electric current, a nerve-current is started brainwards (where it will produce no effect) as well as towards the muscles which it supplies; and the same is true of a sensory nerve. The specific effects depend upon the sense-organ from which its message starts and upon the receiving apparatus to which it delivers it. If a telegraph wire were cut and the sending apparatus, or transmitting key, were moved from the town from which the wire started, to the cut end of the wire, the clerk in charge of the indicator would suppose that any message he received came from the town with which the wire ought to place him in communication, and he would read his message in this belief. That the brain is in the same position is illustrated by a story which Dr Hughlings Jackson told to the Neurological Society in his presidential address. Soon after he had commenced practice, a patient, whose leg had been amputated, sent for him in great distress. "Doctor, do you know what has become of my leg?" "Yes, it is buried in old St Pancras Churchyard." "Then, for heaven's sake, doctor, have it dug up and scratch it just above the ankle."

Having shown that nerve-fibres are incapable of tampering with the messages which they transmit, there remains

only the grey matter of the spinal cord and brain. This consists of nerve-cells lying in a plexus, or feltwork, of filaments derived from the branching of the processes of cells and fibres. This feltwork is of quite inconceivable richness, and it matters little for our present argument whether it be a network in the proper sense of the word—whether its filaments are continuous from fibril to cell-process and *vice versa*—or whether, as is almost universally held at the present moment, they end freely and convey their impulses across from one filament to another which lies near it, perhaps in contact, but not in continuity. At the present time almost all anatomists hold the "Neuron theory." They look upon the elements of nervous tissue as cells, each with one long unbroken process, the nerve-fibre, reaching, it may be, from the spinal cord to the hand or foot, and many "protoplasmic" processes which branch; and they consider that every neuron is absolutely unconnected with all other neurons. As the writer has persistently opposed this theory since it was first formulated, he had better pass over the question as to the nature of the nerve feltwork in silence. Is it the nerve-cells or the nerve-feltwork which manipulates the messages which pass through the grey matter? for all impulses pass through it. Grey matter is the tissue in which they are redirected from sensory into motor channels. Several hypotheses have recently been started to account for the making and breaking of the conducting paths through the grey matter; the protoplasmic processes are supposed to retract and extend; the protoplasm of the cells is supposed to flow out along invisible nerve-fibrils, and so forth; but no one imagines that the feltwork of the grey matter can in any way alter the quality of the impulses which it transmits.

If neither nerve-fibres nor grey feltwork exercise any influence over the quality of the impulses which they conduct, the nerve-cells alone remain to those who wish to see "the god in the machine." And it cannot be denied that physiologists have taken great liberties with the machine. It has turned out every kind of work which their fancy ex-

acted. They have pictured the nerve-cells as doing all their thinking, and they have thought of the nerve-cells as working in the way they pictured. Reading some recent text-books recalls to mind the Irishman who held up the plank he was sitting on. But as far back as 1877 Lewes combated in vigorous language the "superstition of the nerve-cell." Yet, even now, it is not slain. Perhaps it does not deserve to die. Ay, there's the rub! Physiology is the last of the sciences to render itself independent of *à priori* reasoning. We feel, will, enjoy, forego, therefore there must be a mechanism which is capable of feeling, acting, and, latest birth of evolutionary time, deciding not to act. But this conclusion does not justify us in assigning these properties to the nerve-cell. The physiologist of a century ago said, with no misgivings as to the cogency of his argument, "I have come down this morning in a bad temper. Therefore my vital spirits are contaminated. The spleen is the organ which makes black bile. Therefore the spleen has poured black bile into my blood." Poor misunderstood spleen! It is busy day and night in purifying the blood, ridding it of its worn-out blood-corpuscles.

All that physiologists know about the nerve-cell is that it transmits impulses and provides for the nutrition of the nerve-fibres to which it gives origin. And in connection with the latter function a curious point arises. By a nerve-cell, when physiologists and psychologists are assigning to it its functions, is meant a large nerve-cell such as occurs in the anterior horn of the spinal cord or in the cortex of the brain. Striking objects from which it is difficult to divert attention. They are so large and so wonderfully branching, so picturesque with their clean-cut axis-cylinder-process which, after giving off collateral branches in the grey matter, runs an unbroken course perhaps for a yard-length in the trunk of a nerve, and their protoplasmic processes ramifying like the limbs and boughs of an oak, frosted in winter with innumerable spikelets known to anatomists as "thorns." It is difficult to induce the members of an histology-class to withdraw their

eyes from these attractive structures or to pay attention to any others; yet, for every single large nerve-cell, there are scores of nerve-cells of different orders, equally beautiful although extremely minute. What work have *they* to do? The most numerous of them, the "granules," although they are exact reproductions in miniature of the large nerve-cells, are sometimes dismissed as "connective-tissue elements," even by anatomists of the highest eminence, or as "abortive nerve-cells." Yet the only reason we know why one cell is big and another small is that the one is responsible for the nutrition of a large fibre and the other of a little one. There is no reason whatever for thinking that the big cell has the right to modify the impulses which pass through it, still less to originate impulses, while the little cell has no such exalted prerogative. Indeed, we know that some of the largest of nerve-cells, the cells of the ganglia on the posterior spinal roots, do not in any way modify the impulses which pass through, or by, them. If physiologists interpreted the phenomena which they observe in their laboratories in the light of their own science, without any preconceived notions as to what they ought to find, they would discover no evidence that nerve-cells possess any discriminating power. All that we learn from experimental evidence is, that afferent impulses are transmitted by the grey matter of the central nervous system into efferent channels.

Physiology has passed through the same stages as other sciences, but, owing to the importance of its applications, the stage of *à priori* reasoning has been unduly prolonged. It began with few facts and much conjecture. As knowledge accumulated untenable hypotheses were successively abandoned; but theories took their place, which, because more detailed, appeared to be more true. Now it is entering a phase which, to borrow a term from religious controversy, may be called agnostic. We have heard of the automatic functions of nerve-cells, we have seen the nervous system mapped out in a multitude of little centres and offices, upon a strikingly anthropomorphic plan; but now physio-

logists are beginning to acknowledge that they do not know of any function possessed by the nervous system save that of redistributing the forces which are impressed upon the body by the outer world. Truly it has further duties—there is not the least doubt about that—but we do not know how it performs them. Not a glimmer of light has been thrown into the mysterious recesses in which the brain stores its presentations of sense. We know nothing about the mechanism of memory, and memory is a necessary antecedent to any action in which the brain shows initiative. The work demanded of the brain is of three orders. (1) It redirects impulses; (2) it stores impulses and, therefore, when it sets them free again, it appears to initiate them; (3) it manifests the phenomena of consciousness and volition which characterize or constitute the *ego*. As yet experimental physiology has thrown no light upon any process but the first.

Turning to the hand-books of twenty or even ten years ago, we find the elaboration of the nervous system carried to great lengths. All tissues were supposed to manage the daily business of repair and waste, production of an "explosive" metabolite if they are contractile, or of a secernible metabolite if they are glandular, under the direct supervision of nerves specially set apart for their work. Physiologists spoke of motor and inhibitory, vaso-constrictor and vaso-dilator, calorific and frigorific, trophic nerves, glandular nerves, etc., but the search for so many distinct varieties has not been very successful. In the case of one organ, and perhaps of one only, do we see distinct evidence of its activity being influenced by two antagonistic nerves. The heart is a most conscientious slave. Seventy times a minute or thereabouts it beats, as long as life lasts, without any command from the Will. Its fault lies in a slight inclination towards an excess of zeal. It is apt to work too hard, producing a pressure in the blood-vessels which is not good for the system, and leads to strain and consequent dilatation of the heart itself. Therefore we find that while it is stimulated to work by slow-acting and apparently not very forcible sym-

pathetic nerves, it is restrained when necessary by a most peremptory "vagus." If the sympathetic is stimulated, the result is more work with a diminution of the heart's nutritive balance—*i.e.* exhaustion. If the vagus act, it does less work and its condition of nutrition improves. These two nerves have been taken as types of two classes of nerves, the one katabolic, breaking down; the other anabolic, building up. The one leading to the diminution of the reserve of foodstuffs in the tissues, the other to their accumulation. There is some evidence, which we have not space to detail, of the existence of these two sets of nerves in connection with other organs; but comparatively few instances of excitement or restraint can be pointed out which are necessarily the direct results of specific nerves and not the indirect results of the regulation of the blood-supply by vaso-motor action. As Dr Langley pointed out in his address as President of the Physiological Section of the British Association at Dover, evolution is still proceeding, the nervous system is making experiments; all organs are not equally endowed with nerves. "Since in the course of evolution a universal development of motor nerves has not occurred, it is, I think, to be expected that the development of inhibitory fibres should be still less universal." Our knowledge of the anatomy, chemistry, and physiology of the nervous system has enormously increased in the last few years, but our conceptions of its relation to the several organs and tissues of the body are far less precise than they used to be. This is another illustration of the tendency towards agnosticism and a hopeful sign of the suppression of the besetting sin of the physiologist, who expects to find every part of the body's work being done as he would order it in his house or factory or laboratory.

As a last illustration of the direction in which physiological thought is trending, we may point out that the doctrine of the minute subdivision of functions among the constituent parts of the grey matter of the central nervous system has been rudely shaken of late. We have but space for three examples. And first, if the reader will place his finger upon his pulse when he

drinks a glass of water, he will find that while he is drinking the heart beats more quickly. This shows that the impulses which pass through the medulla oblongata and lead to the inhibition of the heart are checked during the reflex action of swallowing. The carrying out of one reflex is therefore associated with the blocking of other reflex paths. Secondly, if the reflex action or pseudo-reflex action known as the knee-jerk is properly investigated, it is found that the passage of the nerve-current which leads to this action, is affected by events which are occurring in far-distant parts of the central nervous system. If, when a person is sitting with his knees crossed and the foot hanging free, the tendon below the knee-cap is tapped, say with a paper-knife or other blunt object, the foot is jerked out without any regard for its owner's wishes. It is possible so to arrange matters that the tendon is tapped with a hammer worked by clockwork at regular intervals for hours together, and at every tap the foot jerks forward. And if, by making the foot move a pencil on a travelling cylinder, a record is kept of the amplitude of the jerk, it is found to vary not only in harmony with the subject's actions, but even with his emotions and thoughts. This shows in a striking way the interdependence, as opposed to the individualization, of the several parts of the central nervous system.

Thirdly, we must call attention to an experiment, recently performed, which puts Müller's theory to a crucial test. One nerve has at last been made to take the place of another. The nerve for the face, which helps to regulate the secretion of saliva and presides over blushing, dilation of the pupil, erection of the hairs, etc.—functions which explain the name of "little sympathetic" given to it long ago—starts from a ganglion in the upper part of the neck. Its fibres have their cells of origin in this "superior cervical ganglion"; but the messages which pass through its fibres are transferred to the ganglion-cells by a long nerve the roots of which come off from the dorsal part of the spinal cord. The vagus nerve has been already alluded to as the nerve of the heart, the stomach, and certain other

viscera. If the nerve which passes up the neck to the superior cervical ganglion be cut out, and the vagus nerve be also cut and turned round, the fibres of the latter reach out along the track of the sympathetic nerve until they enter the ganglion and surround its cells with their branches. Henceforth the vagus nerve, which ought to be supervising digestion and the beating of the heart, controls blushing, dilation of the pupil, and the other actions which formerly were within the province of the cervical sympathetic. It is unnecessary to point out how far-reaching are the conclusions to be drawn from this experiment. It upsets our notions of the specific functions of nerve-centres. It throws doubt upon much that has been accepted as established knowledge, and causes physiologists to pause, and ask whether they may not have devised a scheme of work for the nervous system on a human pattern, instead of contenting themselves with observing how it works.

CHAPTER VI

Microphytology

THIS, the youngest of the sciences, already occupies almost as much space in the laboratories of the world as any of her elder sisters. So young is she that it is doubtful whether her parents have definitely agreed upon a name as yet. Botanists, pathologists, chemists are anxious to stand as sponsors; while brewers, dairymen, indigo and tobacco manufacturers and other wealthy men of commerce are quite willing to act as godfathers if the men of science will consent to stand aside.

The science dates its birth to Pasteur's researches upon fermentation. Pasteur proved that fermentation is not a chemical action in the ordinary sense, but the work of living cells which, in taking from sugar the oxygen needed for their respiration, make such an alteration in its molecule as causes it to break up into alcohol and carbonic acid. The amount of sugar which they consume as food is insignificant as compared with the amount which, by their vital activity, is decomposed. It is these bye-actions which characterize minute organisms. They not merely consume a certain amount of the medium in which they live and obtain oxygen for its combustion from the air, as a larger plant or an animal would do, but they profoundly alter the constitution of the rest. For every ounce which yeast adds to its own weight when growing in a solution of sugar it decomposes about 20 ounces into alcohol and carbonic acid. There are certain minute animals—the number at present known is very small—which produce effects similar to those produced by microscopic plants. Microphytology therefore is not an unexceptionable name, but it is better than the term bacteriology

which is commonly used; since bacteria, properly so called, are not by any means the only organisms with which the science deals. Some common term is needed which would imply that minute organisms are studied, not on account of the intrinsic interest which attaches to their life-history as plants or animals, but because of the importance of their effects. And, judged by the rôle which they play in the drama of Life, these unicellular things, invisible to the naked eye, have an importance far greater than that of the large and conspicuous forms which until recently have monopolized attention. Elephants and whales, oaks and eucalyptus, and all other large animals and plants might disappear without any great change in the habitableness of the globe; whereas, if bacteria and moulds were to cease to be, the surface of the earth would become incapable of supporting life of any kind. Were it not for these agents which restore dead plants and animals to the soil, leaves as they fall would accumulate in a blanket impervious to the rootlets of germinating seeds, and the bodies of animals would dry up until, in the course of ages, they hid the ground from the sun.

Microphytology differs from other sciences, in as much as it is studied not as a pure science, but for the sake of its applications. As a pure science it would be a branch of botany; as applied science it belongs to medicine, as well as to various industries. Of the greatest importance to the human race is the discovery that the entrance of microbes into the body is the true cause of many diseases, and these the most inimical to life. They also cause certain diseases in plants. Again, coming within the province of public health, it is found that the destruction of sewage is due to the same agents. Hence the science is most ardently pursued by medical men. In commerce the proper fermentation of wine and beer, and all the "diseases" to which these beverages are liable, are due to microbes. The successful development of the flavour of butter and ripening of cheese, the preparation of indigo and the curing of tobacco depend upon the use of the most desirable kinds of these minute or-

ganisms. In agriculture the reduction of nitrogenous manures to a condition in which they can be utilized by crops, and even the fixation of free nitrogen from the air to balance the waste due to the escape of nitrogen into the air and into rivers, is again the work of germs. Various other processes might be named to show how many different classes are interested in this study of minute organisms, and to explain the participation in it of many beside, those who first and most naturally undertook it. But there is also another reason. The investigation of bacteria requires very special training in manipulation and staining, as well as in the use of the microscope, and since its importance is most urgent to the students of disease, it naturally follows that they have acquired special skill. Hence the agriculturist, the brewer and the dairyman come to the pathologist for information with regard to the organisms which he, better than they, is qualified to examine.

The study may be divided into (1) methods for isolating and cultivating microbes; (2) the recognition of the specific organisms which are responsible for commercial operations and for disease, and the elucidation of their life-history; (3) the discovery of the reasons for their indirect and often disastrous effects; the methods adopted by their hosts to protect themselves against their action; and the plans which may be devised to aid the host in his warfare with the germs.

1. The isolation of bacteria is a problem in gardening on a very small scale. The soils in which they grow best are gelatin, agar (made from a Japanese seaweed, and especially valuable because, unlike gelatin, it remains solid at blood-heat), broth, serum of blood, etc. Every housekeeper knows that, in summer, a calves-foot jelly begins to liquify and to give off an unpleasant odour within forty-eight hours. It is cultivating bacteria on an extensive scale. If it is desired to determine whether a particular kind of germ is present in the air of a London cowshed, a solution of gelatin is spread upon a plate of glass. This is sterilized by heating to a point at which all bacteria are killed. It is then taken out of the jar (in which it is enveloped by sterilized air),

exposed for a few minutes in the cowshed, and put back into its jar. In two or three days the plate is covered with colonies of bacteria. A gardener's next operation would be the weeding of his bed. This is impracticable in microphytology; but since the several colonies have distinctive forms, it is possible to reverse the process and, so to speak, to "flower" it. A colony, known to be of the required kind, is transferred with a sterilized needle to a tube of sterilized gelatin, and grown by itself. After several transfers a pure growth is obtained which may be cultivated if desired upon a large scale.

2. When the pathologist is seeking for the specific germ of a certain disease he makes pure cultures of every kind of bacterium which he can obtain from the diseased animal or person. If a certain microbe is invariably present he has good ground for suspecting it of being the cause; but there is only one way of proving that his suspicion is correct. It must produce the disease when injected into some animal which is capable of taking it. Having ascertained the nature of the germ which causes the disease, it next becomes the duty of the microphytologist to investigate its life-history. There are two points in particular upon which he needs to obtain information: (*A*) Can the microbe live out of the animal body, or out of its special medium; and, if so, is there any situation, such as water or the soil, in which it is commonly to be found? Does its life as a parasite, that is to say, alternate with a free existence? (*B*) Does it produce spores or does it multiply by cell-division alone.

A. The bacillus of tubercle was at first thought to be capable of a parasitic existence only, because it did not thrive except at temperatures at, or near, blood-heat. It has now been found that, although it does not grow vigorously unless at a favourable temperature, it can maintain a torpid existence under more trying conditions than was, at first, thought possible. On the other hand the bacillus of lock-jaw (tetanus) is, in some localities, a common inhabitant of the soil. Since this terrible pest but rarely finds its way into the animal body a

most interesting problem presents itself. What does the bacillus feed upon in the soil? What relation do its occasional visits to the animal body bear to its habitual residence in the soil? Do myriads of generations pass their lives in the soil in order that, from time to time, a few may be bred in the body? We say generations although it should be borne in mind that these unicellular organisms are not generated, neither do they die. They merely divide. Those which are not destroyed by outside agencies are immortal.

As we have already pointed out, the germs which produce disease are few in number compared with those which never affect animals or Man. Water may teem with microbes and yet be perfectly wholesome to drink. Indeed, in the struggle for existence among these minute organisms the more delicate "pathogenic" microbes usually go to the wall, so that the presence of innocent microbes in large numbers may, under certain circumstances, be a guarantee that none which are noxious have had a chance of survival. Microbes are not man's enemies only, but among the best of his friends.

The bacteria which habitually live in the soil produce results, compared with which the effects of pathogenic germs are trifling, if living things be looked at as a whole. The story of the Kentish farmer who boiled the rags which he used as manure for his hops has often been repeated of late years. Fearing that the dirty rags, which at one time were invariably applied to hop-gardens, might be a source of danger to his family and labourers, he had them cooked in a caldron before they were dug into the ground; but found to his astonishment that they no longer acted as a stimulant to the hops. The rags were useless as manure when freed from the flakes of epidermis and other germ-bearing reminiscences of their *sometime* wearers. Although this story will hardly bear scientific criticism it points a moral. The soil is prepared for the rootlets of plants by three sets of bacteria (*a*) those which reduce organic matter to simple salts which plants can absorb; (*b*) those which oxidize

nitrogenous (ammonia) compounds into nitrites and nitrates; and (*c*) those which fix the nitrogen of the atmosphere. Among the most interesting of the latter are the nitrogen-fixing bacilli which grow in minute nodules on the roots of leguminous plants. Their life is an illustration of genuine symbiosis, the bacteria being housed by the higher plant, in specially made excrescences, for the sake of the services which they are able to render in return. The nodules on the root of a pea are easily seen even without a lens. If one of them is cut, a creamy fluid escapes which is found upon microscopic examination to be loaded with bacilli. How the bacilli do their work has not been ascertained, as yet, but it is certain that they fix the nitrogen of the air which circulates in the interstices of the soil. Farmers have long known that peas, vetches and clovers, better than any other crops, prepare the land for wheat. They were aware, too, of the importance of well stirring the soil to admit air. Now that the explanation has been found it is probable that scientific agriculture will discover means of replacing the nitrogen, which is constantly escaping from the soil, without recourse to artificial manures. Experiments have been made on a large scale in Germany in cultivating nitrogen-fixing bacilli and introducing them with the seed. The use of these cultures has not, however, given good results in England, up to the present time.

B. From a practical point of view it is very important to ascertain whether a microbe produces spores. A temperature of 70° C. kills all microbes; whereas boiling is required to kill their spores. The spores can also resist dessication and oxidation far better than bacteria. The microbes of plague, diphtheria, and pneumonia do not form spores.

3. It has already been stated that most diseases are caused by microbes. They produce not only various fevers but cholera, tetanus, leprosy, tuberculosis, etc., in which a febrile temperature is not the most marked symptom. At present they are being studied chiefly for the sake of finding out how they cause disease and how both men and

animals may be rendered insusceptible, or able to combat the disease if they cannot be prevented from taking it. To what are the ill-effects which follow an invasion by bacteria due? They are certainly due, not to the demand made by the microbes upon nutrient fluids or tissues of the body, but to poisons, called collectively toxins, which they either secrete or cause the tissues to secrete. The secretion of the microbes may be a virulent and speedy poison, or it may act indirectly, leading to decomposition of the body cells and juices with consequent formation of poisonous substances. In diphtheria, for example, the bacilli live in the mucous membrane of the throat. The substances which they produce resemble ferments in many ways, particularly in their sensitiveness to heat. Although not poisonous in themselves these ferments when absorbed into the blood induce the formation of poisons to which all the constitutional symptoms are due. After the patient has recovered from the local symptoms in the throat he may succumb to the degeneration of his nervous system which the toxins set up.

What the microbe gains by destroying its host is a problem as yet unsolved. It seems like a premature attempt to carry out the great mission of bacteria of returning all organized beings to the soil.

In the struggle with its invaders the organism wins in the long run; but myriads of individuals die before immunity to any form of disease is acquired by the race. The progress which is being made towards the acquisition of a power of resisting disease is strikingly shown in the innocence of measles among the white races compared with their virulence when introduced into the South Sea Islands and other places where they were previously unknown. No diseases are restricted to definite geographical areas in these days of free communication; but there is evidence that even within historic times the evolution of human beings has tended to protect them against those forms of germ to which they were especially exposed, while the evolution of the germs has resulted in the production of new forms of disease.

The animal body counteracts the toxins which microbes produce by developing within its tissues and juices a class of substances to which the collective name of antitoxins has been given. Take diphtheria as an example. When a susceptible animal, such as the horse, is inoculated with the diphtheria-toxin it exhibits symptoms of the disease. If the dose is small the horse recovers. After an interval (of say five days) a larger dose of the toxin is required to produce disturbance. Eventually, an unlimited dose may be given without effect. It is immune because its blood is charged with antitoxin. And now, if some of its blood-serum, which has been perfectly sterilized so that it will keep for weeks or months, is injected beneath the skin of a child suffering from diphtheria, the antitoxins of the horse reinforce those which the child is making for itself and enable it, if the case has not advanced too far, to antidote the toxins of the disease.

Vaccination confers immunity in a somewhat different way. For some reason, which is not as yet satisfactorily explained, after one invasion of a particular kind of germ the subject is proof against further attacks. A second attack of small-pox is very rare. Persons who have had tuberculous glands in youth seldom contract tuberculosis of the lungs. Typhoid fever, scarlet fever, etc., may attack a second time, but the second attack is not likely to do much harm. For more than a century people preferred to inoculate themselves with small-pox, securing a mild attack when the system was not predisposed to the disease, rather than run the risk of an attack under unfavourable circumstances; but "variolation" was prohibited by Act of Parliament in 1840 because the inoculated person was a focus of the disease. Although he might secure a mild attack for himself he was just as likely as any other small-pox patient to distribute the disease in a virulent form to his attendants. In 1796 Jenner made the great discovery that inoculation with small-pox which, at some period in its history, had been transmitted to cows (animals which are comparatively immune) and had

thus become attenuated, produced a mild attack of "cow-pox" which is a perfect protection against small-pox. The person so affected cannot spread the unattenuated disease.

In the treatment of hydrophobia the virus is attenuated in a different way. The spinal cord of a rabbit which has died of the disease is dried. A broth-culture is made from the dried cord and the patient is inoculated with this. He is thus rendered immune before the attack of hydrophobia has had time to supervene. Fortunately, a long interval elapses between the bite and the development of the disease. The same treatment would probably be applicable to lock-jaw if it were possible to ascertain, in any given case, that the germs had been introduced into a wound. Cholera is anticipated and disarmed by inoculating a person with a culture of the cholera-spirillum which has been weakened by cultivation in broth or agar. Plague is stayed by introducing into the system of those who have not yet been attacked a sufficient dose of plague-toxins prepared from a culture of the bacillus which has been killed by heat. The inoculations just described illustrate four different methods of securing immunity.

How it is the antitoxic results of an invasion remain in the system for years after the germs have been defeated is a problem which still awaits solution. It seems impossible that the antitoxins formed at the time of an attack should be stored for long. Rather must we suppose that the tissues are in some way trained to produce them as required. For a long time pathologists have looked upon the white blood-corpuscles or leucocytes as the body's medical officers of health. Undoubtedly they have the power of catching and devouring germs or any other foreign particles which may force admittance. Their independent existence, and the situation of their camps, points them out as Nature's police. Their breeding grounds are the tonsils at the entrance to the throat, the submucous tissue of the wind-pipe and bronchi, Peyer's patches in the intestine, the glands of the neck, the armpit, and the groin, which guard the outflows of lymphatic vessels, and bar the passage into the blood-stream and the vital organs.

When the throat is sore the tonsil enlarges, and the leucocytes can be seen to sweep down from their fortress, to work their way among the cells of the mucous membrane, and even to reach its surface in their eagerness to give battle to any noxious germs which might try to force an entrance into the connective tissue which lies beneath it. They patrol the blood-vessels to the number of about one leucocyte for every three hundred red blood-corpuscles; now rolling down the blood-stream, now clinging to the vessel-wall and squeezing themselves between its lining cells in search of effused blood or broken-down tissue which would set up mischief if not speedily removed. They are entirely independent of nervous control, are as free to wander within the body as an amœba in a pond. The best of our nutrient juices are at their command. They are fed as no fixed tissue-cells are fed. And in return for this hospitality, they do, as far as we know, no work, save that of removing dead or foreign particles. Our contract with them resembles that made by the Saxons with the Danes. They are free to take what toll they choose so long as they protect us against all other robbers. Serum which contains antitoxins is equally effective whether leucocytes be present or no; but it is not improbable that the leucocytes add to their services in catching germs, the further service of secreting antitoxins. It may be that in some incomprehensible way a successful invasion trains them to resist in future the strategy of the invading host.

Of greater importance to the human race than plans for aiding the system in its combats with the germs, are the measures which may be adopted to prevent their intrusion. One out of every nine of the population of Great Britain is slain by the tubercle-bacillus. Yet this invisible foe, if once we realized its existence with the same vividness with which we recognize beasts of prey might be stamped out, as the wolf was stamped out of England. If with the mind's eye we could see these microbes swarming in the milk we give our children, we should free our cattle from tuberculosis. If we once grasped the fact that, with each expectoration a

phthisical patient scatters millions of their spores, we should insist upon the burning of all tuberculous sputa, or their disinfection as they leave the mouth. Can it be said that these ends are unattainable? Already Denmark has purged its herds of the disease. Paper handkerchiefs can be burnt. Spittoons can be supplied with thymol or carbolic acid. And what would become of the bacillus if these simple precautions were faithfully carried out? It cannot, like many microbes, live in either soil or water. It has no source of livelihood other than the juices of the body.

At a reception in Vienna it was said, most justly, of Lord Lister that he had saved more lives than the Franco-German War, then recently ended, had sacrificed. When he introduced carbolic spray and antiseptic dressings old-fashioned surgeons resisted the new treatment. Pointing to cases in which their precautions failed to prevent the septic infection of wounds, they claimed that the majority of patients did better with clean dressings, frequently removed, than with the new swathings of wool and gauze which, for all the surgeon knew, were shutting germs of septicæmia in the wound, instead of keeping them out. Slowly they realized that if there were any germs under the dressings they had found access owing to the neglect of some precaution. Beneath his finger-nail a surgeon can carry germs sufficient to render nugatory all Lister's antiseptics.

Their extreme minuteness—they average, perhaps, about three or four hundredths of a millimetre in length by less than one thousandth of a millimetre in breadth—makes it extremely difficult to keep germs out of wounds or to make sure that they have had no chance of infecting food; for microbes can pour through a pin-prick in a sheet of paper faster than rats through a barnyard gate. And when they find admittance their effects are extraordinarily certain. Fifty-seven houses in Bristol were supplied with milk which came from a farm where the milk-cans were washed in water contaminated by typhoid germs. Typhoid fever broke out in forty-one of these houses. In India it has

happened more than once that every person who partook of cholera-infected food has been attacked with the disease. There is no limit to the care which must be taken. At a certain officers' quarters every hygienic precaution which could be thought of was adopted. The servants were not allowed to leave the camp. Serviettes and table-cloths, as they came home from the laundry, were carefully disinfected; but the native servants rinsed the dish-cloths in an infected stream. A jelly was set in a carefully wiped mould, and all who partook of it were attacked by cholera. There is such a thing as mischievous cleanliness. It looks so immaculate that it is apt to withdraw attention from the real source of danger. The brightness of a can is no warrant for the purity of milk.

Fortunately there is a treatment to which all microbes are ready victims. They are easily killed by heat. None can survive a temperature of 70° C., and boiling destroys all kinds of spore. A boiled bacillus is an insignificant thing. A living germ is better (or worse) than a dead lion.

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